Public Interest Energy Research (PIER) Program

FINAL PROJECT REPORT

OFFICE DAYLIGHTING POTENTIAL

Task 3 of the PIER Daylighting Plus Research Program

Prepared for: California Energy Commission
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The project was managed by the Heschong Mahone Group (HMG), with Mudit Saxena as principal investigator and project lead responsible for the overall project research direction, method development and analysis. Timothy Perry was the technical analyst and ran the daylighting simulations, developed the façade templates, and managed the data processing. Charlotte Bonneville was the data analyst and provided statistical analysis of California Commercial End-Use Survey (CEUS) data, development of façade templates and analysis of the simulation results. Michael Maroney provided assistance in data analysis and Ramana Koti helped in the development of the simulation models. Lisa Heschong provided technical oversight and overall project guidance. Abhijeet Pande was the program manager for the Daylighting Plus program.

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PREFACE

The California Energy Commission Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Office Daylighting Potential is the final report for the Office Daylighting Potential project, Contract Number 500-06-039, conducted by Heschong Mahone Group, Inc. The information from this project contributes to PIER's Buildings End-Use Energy Efficiency Program.

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ABSTRACT

Daylight in existing buildings represents a vast untapped resource for energy and demand savings. This project estimated the demand and energy savings potential that could be achieved by adding photocontrols (controls which reduce or eliminate the use of electric lighting when sufficient daylight is available) to existing daylit office spaces in California. The project also quantified additional savings that could be achieved through additional daylighting enhancements. The California Commercial End-Use Survey (CEUS) dataset of 536 existing office premises provided a basis for the analysis, which used Radiance-based annual daylighting simulation and a new façade-templates-based method.

The project identified concerns with the glazing characteristics used in the CEUS dataset, and collected additional information on window and exterior shading characteristics.

The results from the simulation exercises show that adding photocontrols to all daylit areas in office buildings existing as of 2002 within the combined investor-owned utilities and Sacramento Municipal Utility District territories would result in a potential savings of 458.5 gigawatt hours (GWh) of energy per year and 184.2 megawatts (MW) of peak demand. The results are also reported by utility and climate zone, by building size, by window-to-wall ratio, and by control type. The average daylit zone only lighting energy savings for all office spaces was 2.11 kilowatt hours/square foot year (kWh/sf-yr) and peak demand reduction was 0.75 Watt/sf. The average whole building energy savings calculated per square foot area of office building area was 0.70 kWh/sf-yr and peak demand reduction was 0.29 W/sf.

The project also identified improvements from various daylighting enhancements such as increased interior reflectances (using lighter colored surfaces which increase light levels due to a greater percentage of light striking that surface being reflected back), reduced furniture partition heights, and addition of light shelves. Building types and physical characteristics of office spaces that offer the greatest opportunities for savings were identified as potential target audits or utility retrofit programs.

In addition to showing the significant energy savings potential in California office buildings by utilizing daylighting controls and strategies, this research informed the 2013 Title 24 Building Energy Efficiency Standards. The detailed energy saving estimates in this project provided justification to mandate photocontrols in daylit zones of commercial buildings. These standards will be effective in 2014 and are estimated to save California ratepayers about $100,000,000 the first year implemented.

Keywords: Existing office buildings, daylighting, energy savings, demand reduction, statewide savings estimate, daylighting improvements, Radiance, Dynamic Radiance, façade-templates

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EXECUTIVE SUMMARY

Daylight in existing buildings represents a vast untapped resource for energy and demand savings. The presence of windows, shading devices, and controllable lighting circuits in California buildings are a large investment by developers and building owners that, in most cases, is not currently exploited for its demand and energy savings potential. This report focuses on existing office buildings and their potential for reaping additional energy and demand savings from daylighting.

The California Commercial End-Use Survey (CEUS) and its detailed dataset of existing buildings provided a basis for the analysis. The 2006 CEUS data used in this study included 536 existing office premises in investor-owned utilities (IOUs) and Sacramento Municipal Utility District (SMUD) territories through 2002, representing about 77 percent of the total state electricity load for that sector. The CEUS dataset provided important information about a representative sample of buildings for the state. It also presented serious limitations for daylighting analysis, as discussed in this report. The project team collected additional data that was not part of the original CEUS data but greatly improved the analysis method by using an improved Dynamic Radiance annual daylighting simulation tool.

The additional data provided the team with better insight into office building types, window layouts, and exterior obstructions, factors that had not been previously analyzed. The results revealed that 75 percent of office square footage in California is low-rise, specifically under four stories, which contradicts many peoples' image of office space as existing primarily in downtown high-rise buildings. The study also found that 60 percent of California office buildings have some form of shading from trees. Other analysis showed that exterior obstructions block a view of the sky up to an average of 24 degrees above the horizon. These findings suggest that energy modeling and program estimates should account for the reality of exterior obstructions such as trees and other buildings, since these existing obstructions have a significant effect on both daylight availability and solar heat gain.

The simulation exercise results show that adding photocontrols (controls which reduce or eliminate the use of electric lighting when sufficient daylight is available) to all office buildings existing as of 2002 within the combined IOU and SMUD territories would result in a potential savings of 458.5 GWh per year and 184.2 MW of peak demand. Thus, for example, if a statewide IOU retrofit program incentivizing the installation of photocontrols could achieve 10 percent market penetration, it could provide up to 45.9 GWh of annual energy savings and 18.4 MW of peak demand reduction. Net-to-gross calculations and operational adjustments should also be considered when evaluating this estimate. The energy and demand savings potentials were also calculated separately by each utility territory and climate zone and are provided in the various results sections and appendices of this report. The study also identified the building types and physical characteristics of office spaces that offer the greatest potential for savings from a utility retrofit program.

The energy savings per square foot of building, or per daylit space, vary considerably, based on many factors, such as climate, location, the layout of the building, and its façade characteristics.

Lighting energy and whole building energy savings are reported per square foot of building and daylit space, separated by small versus large office, and by window-to-wall ratio (WWR). *Whole building* energy savings for all office buildings in California, calculated per square foot of office building area, averaged 0.70 kilowatt hours/square foot year (kWh/sf-yr), and peak demand reduction averaged 0.29 Watt/square foot (W/sf). For small office buildings with larger window areas, these values rose to 0.95 kWh/sf-yr and 0.39 W/sf. When looking at the primary daylit zone only, average *lighting* energy savings for all office spaces was 2.11 kWh/sf-yr, and peak demand reduction was 0.75 W/sf. These values rose for small office buildings with larger window areas to 2.38 kWh/sf-yr and 0.76 W/sf. These estimates are based on the individual operating schedules and site conditions for each of the 536 office buildings in the CEUS database, extrapolated up to the statewide population. Other than the addition of bi-level switching photocontrols, the estimates do not include any other improvements to the physical spaces or to the existing lighting system.

The results also show that for all existing office buildings, an average of 23 percent of the building area was in primary (area in which daylighting can substitute all electric lighting) or skylit daylit zones, and 31 percent of the building area was in all daylit zones. It was also found that 76 percent of the potential daylighting savings came from the primary and skylit daylit zones alone.

New control technologies and existing infrastructure revision opportunities in California make this opportunity more cost-effective. Recent cost reductions in photo controls and controllable ballasts, the ability to control more than one circuit with a single sensor, and the introduction of wireless controls have all greatly reduced the cost of adding photocontrols to existing buildings. The requirement for separate switching of at least one-half of the electric lighting in a daylit zone, which has been required in California's energy code since the early 1990s, provides an existing infrastructure ready-made for retrofitting with automated controls.

The project also estimated how much additional savings was possible if physical improvements were made to enhance daylight availability. The improvements that the project team investigated were limited only to those that could be easily made to existing buildings, such as reducing furniture partition heights, increasing interior surface reflectances, or adding interior light shelves. Increasing interior surface reflectances showed the most consistent improvement in savings across all types of office spaces modeled, regardless of window size or furniture type. Simply repainting walls, replacing old ceiling tiles, and recarpeting with higher reflectance products can increase average energy and demand savings by about 15 percent.

Reducing furniture partition heights from 60" to 45" and 60" to 30" also showed significant energy savings improvements, particularly in those spaces with larger window areas. For those spaces with net WWR greater than 40 percent (such as those with greater than 40 percent glazing area to floor-to-ceiling exterior wall area), reducing furniture heights from 60" to 45"increased energy savings by 10 percent, and reducing heights from 60" to 30" increased savings by 14 percent. Thus, lower furniture partition heights can play a significant role in increasing daylighting energy savings.

Finally, the project uncovered a number of serious issues with the glazing characteristics used in the 2006 CEUS models as well as with the automated daylight zone generator in eQuest (energy simulation tool). Both of these issues have been communicated to the respective authors so that they can be improved.

In addition to showing the large energy savings potential in California office buildings by utilizing daylighting controls and strategies, this research informed the 2013 Title 24 Building Energy Efficiency Standards. The detailed energy saving estimates in this project provided justification to mandate photocontrols in daylit zones of commercial buildings. These standards will be effective in 2014 and are estimated to save California ratepayers about $100,000,000 the first year implemented.

CHAPTER 1: Introduction

This report provides a description of methodology and results from the Office Daylighting Potential project, a part of the Daylighting Plus PIER program. The report has been organized into four main parts:

1. The first section on data collection and dataset analysis (Chapters 20 and 3) describes analysis of the California Commercial End Use Survey (CEUS) dataset, which was used as the primary basis for this study. It presents some basic statistics of key physical characteristics of offices spaces found in the CEUS dataset, such as window to wall ratios, window and space characteristics and so forth. This section also documents some important limitations of the CEUS dataset for use in a daylighting analysis, and how those limitations were overcome for this study through additional data collection. The section also provides basic statistics of the additional data collected.
2. The section on methodology (Chapter 4) describes the new analysis approach using façade-templates, developed by the project team to run daylighting simulations. The section also explains photocontrols assumptions and methodology of converting hourly daylighting illuminance from Radiance simulations to lighting energy use, and whole building energy use for spaces in the CEUS dataset.
3. The section on analysis and findings (Chapter 5) presents the results from the simulation runs and analysis. Results are provided for adding photocontrols and for physical improvements to the space. Savings are presented as total technical potential of daylighting savings for the state of California, as well as average per square foot of daylit zone area, daylit space area and building area.
4. Finally, a section on conclusions and next steps (Chapter 6) provides a discussion of what these results mean for utility retrofit energy efficiency program opportunity, as well as codes and standards improvements. The section also provides a discussion on improvements to CEUS, and next steps to develop the façade-templates approach.

1.1 Background on the Daylighting Plus Program

The Daylighting Plus PIER program aims to promote better understanding of daylighting potential, strategies and metrics with the aim to increase energy savings from daylighting and associated electric lighting in commercial buildings in California. This was achieved through a coordinated set of research projects and related market connections activities.

Led by the Heschong Mahone Group, Inc., the Daylighting Plus program consisted of four program elements addressing the appropriate use of daylight:

- The Office Daylighting Potential Project addressed by this report, set out to quantify the market potential for retrofitting existing office space in California to maximize daylighting energy saving potential, and develop assessment tools for new daylighting retrofit programs.

- The Daylighting Metrics Project, worked with the IESNA and an international team to develop and test new daylight performance metrics and criteria, based on annual simulations. The goal is for these metrics to provide better criteria for appropriate daylighting design, tailored to climate, building operating characteristics, and advanced design options, which can then be adopted into codes and voluntary standards.
- The Retail Revisioning Project worked with Federated Department Stores and other retail designers and owners, to develop and demonstrate daylighting design approaches for "fancy box" retail stores that can both enhance visual marketing and provide significant energy savings.
- In addition, a program-wide market connections effort assisted the project-level objectives by hosting outreach events and forums for discussion of the range of issues addressed by this program, and of concern to the PIER Program. These activities facilitated the exchange of knowledge generated by this program to the appropriate audiences, and generated further discussions and market connections among the participants.

Reports for the other three Daylighting Plus PIER elements will be available from the California Energy Commission at http://www.energy.ca.gov/research/.

1.2 Introduction to the Office Daylighting Potential Project

Existing buildings offer a unique opportunity for energy savings from daylighting. Most buildings are designed with windows to admit daylight and provide view to the outdoors as an amenity for a healthy and productive indoor environment. Daylight is thus available in most buildings. However the extent to which this available daylight can be used to produce useful energy savings from turning off electric lights, has not been well studied.

This project focused on existing office buildings and studied their potential for energy and demand savings from daylighting. Existing office buildings are a prime candidate for daylighting energy savings and demand reduction, as offices are occupied during most daylit hours, and have one of the highest total energy consumptions among commercial building categories (CBECS, 2003).

This project leveraged the California Commercial End-Use Survey (CEUS) and its rich dataset of existing buildings to obtain information about physical characteristics of existing office buildings in California and their lighting energy use schedules. The project team used a radiance based annual daylighting simulation approach to determine daylight availability for each offices space in the CEUS dataset, and then calculated the energy savings potential that could be realized by adding photocontrols to these existing daylit office spaces. The team also estimated how much the savings estimate could be improved by making additional physical improvements to these spaces.

To support the analysis process, the project team also collected additional data about existing office buildings in California, mainly on window layouts and exterior obstructions. This data was used to augment the CEUS dataset and improve the precision of the daylighting analysis.

1.3 Goals of the Project

The project's primary goal was to develop an estimate of potential energy and demand savings from daylighting in existing office buildings in California. This is the energy savings that could be realized if photocontrols are added to existing spaces, without changing any other physical attribute of the space. Another project goal was to estimate additional energy and demand savings from improvements made to spaces to enhance daylighting. The improvements that the project team investigated were limited to those that could be easily made to existing buildings, such as reducing furniture partition heights, increasing interior reflectances and adding light shelves.

Calculation of cost effectiveness of adding either photocontrols or any of the suggested physical improvements was not within the scope of this study. The study only provides energy savings estimates for electric lighting, and the associated changes in HVAC energy use, resulting from the reduction in lighting energy use with the addition of photocontrols in daylit areas.

The project team expects the results from this study to be useful in assigning statewide policy priorities to the improvement of energy efficiency of existing buildings. The results offer an energy efficiency strategy that addresses daylighting. Similar studies for other strategies can help prioritize investments for building owners, utility energy efficiency programs, as well as suggest improvements for building codes and standards development. The study also provides market potential data for manufacturers of photocontrols, advanced daylighting optimized fenestration systems, light shelves, and so forth.

1.4 Research Plan

To achieve the goals of this project, a research plan was developed to collect detailed data about the physical geometries of existing offices spaces in California from CEUS. Daylight availability in each office space in the CEUS dataset was then calculated using Dynamic Radiance, a Radiance-based annual daylighting simulation approach. The results from these annual simulations were then used to modify existing electric lighting usage schedules of each office space from the CEUS dataset, to represent lighting schedules of the spaces with photocontrols. Energy and demand savings were then calculated and extrapolated to a statewide savings estimate, by each utility territory and climate zone.

Working within the constraints of the project, the project team developed an innovative approach of using 'façade templates' to tackle the challenge of running a large number of annual daylighting simulations with Radiance on the CEUS dataset.

The basic components of the research plan were:

- Statistical analysis of physical attributes of office buildings in the CEUS dataset
    - Performing a statistical analysis provided an understanding of how various physical attributes of offices spaces such as window-to-wall-ratio, ceiling height and so forth. varied across the population of office buildings in the state. This became the basis of developing the façade templates approach, which simplified the range of existing facades into a set of typical configurations.
- Development of façade templates that were representative of exterior facades in the CEUS dataset
    - A sufficiently large number of façade templates were developed to represent various combinations of physical characteristics of facades in the CEUS dataset.
- Annual daylighting simulations using the Dynamic Radiance approach on template-spaces
    - Annual daylighting simulations were run for the façade templates by attaching them to either large or small template-spaces with typical office furniture layouts. The annual simulations produced results of daylight availability for each template space.
- Development of modified lighting schedules based on daylight availability and photocontrols
    - Results from annual simulations of each façade template were mapped to each exterior façade in the CEUS dataset to determine daylight availability for each space in the dataset. The lighting schedule of each space was then modified based on the daylight availability results from the annual daylighting simulations, assuming up to a maximum of three-zone control with either dimming or 2-level switching photocontrols.
- Extrapolating energy savings results to a limited statewide estimate
    - Once modified lighting schedules were generated for each office space in the CEUS dataset, energy and demand savings were calculated for lighting as well as associated HVAC energy use. These savings estimates were then extrapolated to statewide estimates using 'expansion weights' for each CEUS building, as provided in the CEUS database.

CHAPTER 2: Data Collection

The data collection activity described in this section involved a review of available commercial building databases to determine the most suitable database for a daylighting study and a detailed review of the selected CEUS database. The project team looked for a database of existing buildings that could provide detailed information about the physical attributes of office spaces that affect daylighting. These attributes include:

- Building size, height, climate zone location, and space types and sizes.
- Exterior façade information such as orientation, window or skylight size and placement, sill heights, head heights, glazing VLT, blinds or shades type, and overhangs
- Lighting power density, operation schedules and control systems by space
- Interior space descriptions such as ceiling height, space width, interior reflectances, and office furniture layout
- Exterior shading elements such as trees, other urban shading structures like neighboring buildings, and screens or awnings

The project team reviewed the following commercial building databases to determine if they provided the required data for the study and the detail in which this data is available:

- Database of Energy Efficiency Resources (DEER)
- US Energy Information Administration's Commercial Buildings Energy Consumption Survey (CBECS)
- California Commercial End-Use Survey (CEUS)
- Non-Residential New Construction (NRNC)
- Heschong Mahone Group's (HMG) Survey of Office Spaces for the Sidelighting Photocontrols Field Study

Based on the initial screening of the databases listed above, the CEUS database was selected as the basis for this study because it provided the richest dataset with actual physical attributes of 536 office premises in the form of eQuest (DOE 2.2) models. Detailed information collected from these 536 office premises such as lighting power densities, lighting and occupancy schedules was also available. Although CEUS provided the richest dataset, it also had some severe limitations. These limitations and how the project team addressed them are discussed later in this section.

2.1 CEUS Database Review

The California End Use Survey (CEUS) is a comprehensive study of commercial sector energy use, primarily designed to support the state's energy demand forecasting activities. This section provides pertinent information about the CEUS dataset as it relates to this study, and also discusses some key limitations of the data from the CEUS.

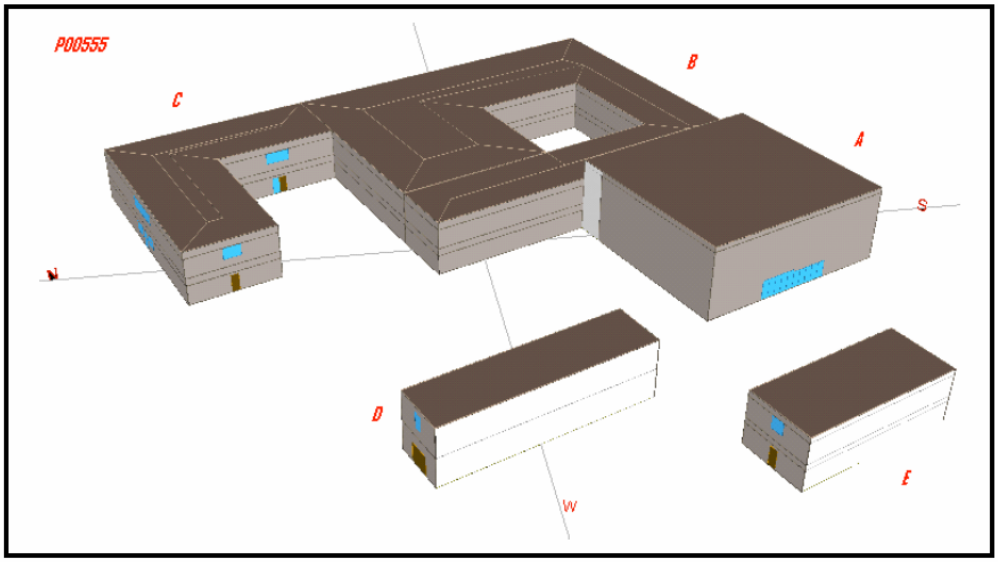
Itron performed the most recent CEUS survey under contract to the California Energy Commission, published on March 2006 (CEUS, 2006). The CEUS database was completed in 2005 and provides a snap-shot of energy use in existing commercial buildings in California for the year 2002 (except SMUD territory that uses a 2003 commercial frame). The CEUS project compiled on-site surveys of 2,790 existing commercial facilities that capture detailed building systems data, building geometry, electricity and gas usage, thermal shell characteristics, equipment inventories, operating schedules, and other building characteristics.

The sample was stratified by utility service area, climate region, building type, and energy consumption levels. Buildings, or premises, were selected to represent typical establishments in the service areas of Pacific Gas and Electric, San Diego Gas & Electric, Southern California Edison, Southern California Gas Company, and the Sacramento Municipal Utility District. Population weights were provided in the data set to expand each premise to represent its proportion of the full population of its utility territory. The CEUS dataset is properly referred to as a 'limited-statewide" sample, but for convenience in this report it will be called simply "statewide".

The three investor owned utilities (IOUs) together represent 72 percent of statewide electricity use, and SMUD represents about another 5 percent, so together, this CEUS data set represents about 78 percent of the full statewide electricity use. The Los Angeles Department of Water and Power (LADWP) and the other municipal utilities represent the remaining 22 percent of the state not included in this analysis.

The CEUS project generated eQuest (DOE2.2) simulation models automatically from the on-site survey data. These eQuest models, for the 'Office' building type (536 office facilities), were made available to the HMG team, by special request to the CEC, for this project. This on-site survey data and subsequent eQuest models for the office facilities are hereafter referred to as the 'CEUS dataset'.

Figure 1: 3D View of Premise-Level Building eQuest Model (From CEUS Final Report)



The CEUS dataset of office buildings is represented by 536 eQuest models, referred to as office **"**premises". A premise is defined in the CEUS Report as 'a single commercial enterprise operating at a contiguous location'. A premise may consist of more than one "component**",** defined in the CEUS report as an 'area used for subdividing a premise into two or more areas unique enough to warrant individual simulation'. This may be loosely interpreted as a floor in a multistory building or any replicable portion or a building that can have a multiplier (component multiplier) applied to its results to extrapolate to a premise.

The components are further composed of "spaces" which are defined as HVAC zones in the eQuest models. It's important to note here that an HVAC zone does not necessarily represent a space as defined normally by floor-to-ceiling partitions, however for lack of any further detail of interior layouts, an HVAC zone is considered equivalent to a space. The spaces each have an assigned lighting power density and a lighting and occupancy schedule, and are typically connected to an HVAC system. Spaces were identified as "daylit spaces" and "non-daylit spaces" based on whether a space had at least one external wall with window(s), or roof with skylight(s).

Table 1 provides a total count of office premises, components and spaces - daylit and not daylit. Another important variable provided in **Table 1** is the number of exterior facades in all daylit spaces with windows. The number of exterior facades with windows is the basis for the "template approach" explained later in Section 4.1.

Table 1: Total Count of Office Spaces and Facades in CEUS

	Total Number in CEUS Dataset
Office Premises	536
Office Components	843
Office Spaces (Daylit and Non-Daylit)	5,336
Daylit Office Spaces	3,578 (67%)
Non-Daylit Office Spaces	1,758 (33%)
Total number of Exterior Facades in All Office Spaces	7,979
Exterior Facades with Windows	6,159 (77%)
Exterior Facades without Windows	1,820 (23%)

The CEUS dataset also provides a multiplier at the premise level (called expansion weights or case weights) which extrapolates results from each premise (eQuest model) to a 'limited statewide' estimate. Chapter 6.2 of the CEUS Final Report provides a detailed explanation of expansion weight, how they were developed and how both electric and gas estimates from CEUS are strictly limited to the covered electric service areas.

2.2 Note on Limitations of the CEUS Dataset

This section provides an explanation of some key limitations of the CEUS dataset, and a discussion how these limitations affect this study.

The CEUS dataset provides unique and extremely valuable information for analysis of energy use in existing building. The survey to collect the information on the buildings' physical characteristics and the subsequent eQuest models were designed with a goal to provide accurate annual building energy use, which is mostly dominated by lighting, cooling, heating and office equipment end uses. The survey hence made directed effort to increase accuracy of the key variables that affect these end uses.

However, since only a very small percent of office spaces had photocontrols (<0.1 percent) and used daylighting in the CEUS dataset, those variables that affect accurate modeling of daylighting were either not captured in the survey, or collected only as average values if they improved HVAC loads estimations. The following is a list of the variables that were not well described in the CEUS dataset, but were of significant importance for a daylighting study.1. **Space Definition:** A space defined in a CEUS eQuest model is an HVAC zone. In most cases this does not correspond to a 'physical space' as defined by floor-to-ceiling partitions, or interior walls. From a daylighting analysis perspective, this is an important limitation. In office spaces with private offices immediately next to a façade this is likely to create an overestimation of daylighting savings. Also such physical spaces may have different LPDs, which is only captured as an average for an HVAC Zone in an eQuest model.

2. **Grouping of Windows on Façade**: Total area of windows on a façade, and window's orientation are important factors to estimate heating and cooling loads. However it is not critical from the HVAC loads perspective, to capture the layout of the windows on each façade, as long as the area totals are correct. However for a daylighting study, the extent to which daylight spreads across a façade depends on how the windows are laid out on the wall. For example, the same wall can have a floor to ceiling window (curtain wall) in the middle 1/3rd of the wall, or a strip window that runs across the length of the wall, both with the same window area. The U*A value (U- insulation, A- area) of the window-wall combination would be the same in both cases, so the heat loss and gain from it is the same, but the two will have a very different daylighting result. On close observation of the eQuest models, it was determined that most eQuest models were designed to capture the total window area per wall in one large window per facade, hence losing the window layout detail. This was later confirmed by the Itron team, that using one large window per façade, as shown in **Table 1**, was a strategy employed to reduce modeling time, with minimal loss in HVAC modeling accuracy.

3. **VLT of Windows**: The project team found that about three quarters of the windows in the office models had been assigned a VLT of 0.90, clearly an incorrect value. This unusually high number meant that appropriate information about window tint (or VLT) had not been captured in the eQuest models. This is the most severe limitation of the current CEUS dataset as it would greatly overestimate daylighting compared to reality, and would also inappropriately calculate solar heat loads for HVAC systems. This issue is further discussed in Section 2.1.1.

4. **Exterior Obstructions**: It's common knowledge that most windows and façades have some sort of exterior obstructions to incident solar radiation and daylighting. These are usually trees or other neighboring buildings. However it is also common modeling practice to leave all obstructions out of the energy simulation models. The reasoning behind this omission has been that exterior obstructions may be temporary, and also that omitting exterior obstructions only adds conservatism to the heating and cooling load estimates, creating a worst case scenario. From a HVAC design view point, this may be acceptable, although it probably overestimates cooling loads and underestimates heating loads. However from a daylighting perspective, this clearly impacts daylight availability in a space, and also overestimates the need for blinds operation. The CEUS on-site surveys and eQuest models did not capture information on the exterior obstructions.

5. **Window Blinds/Shades (Interior Attachments):** Blinds and shades have only a limited impact on HVAC energy use. Blinds can reject a portion of solar radiation incident on a window, but the rest is absorbed and remains in the conditioned space. However a model without blinds or shades will create a very unrealistic daylighting model. Such a model will over predict available daylighting in a space. It hence becomes very important to not only model blinds and their light transmittance properties, but also to model a blinds operation schedule.

6. **Interior Surface Reflectance**: Similar to furniture, interior surface reflections, or color of the floor, wall and ceiling too has no significance in a model to predict building HVAC and scheduled lighting energy use. But for daylighting analysis, interior surface reflectance plays an important role in determining illuminance levels in the space.

7. **Furniture Layout and Height**: Furniture has limited or no importance in a model to predict building HVAC and scheduled lighting energy use, and hence was not captured in the CEUS on-site surveys. However for daylighting analysis of a space, this becomes a very important factor. A space with 60″ high furniture is likely to have limited daylight penetration from an external façade, but the same space with 45″ or 30″ high furniture will have a much deeper daylight penetration.

CHAPTER 3: CEUS Dataset Analysis

The project team had to first understand the physical characteristics of office spaces and facades and how they varied across the statewide population to determine a methodology for a study on the daylighting potential of office buildings. For this, the team conducted a statistical analysis on a set of physical characteristics that relate to daylighting. This section provides an overview of the findings from this statistical analysis. In addition to this analysis, to address the limitations in the CEUS dataset identified in Section 2.2, the project team collected additional data mainly related to window layouts and exterior obstructions. This section also provides results from statistical analysis done on this data.

The project team collected detailed data from two sources to run statistical analysis on data in CEUS.

- The first source was information from the on-site surveys to each of the 536 office premises, obtained by the project team by request to Itron. This data was provided in the form of an Access database.
- The second source was BDL (building description language) files of the eQuest simulation models. Each BDL file that accompanies the eQuest models described the geometry of the building and provided the key parameters such as hourly schedules, lighting power densities, and so forth..

The data was first processed to compute certain building characteristics of interest, for example gross window-to-wall ratio is a variable of interest for this study. This was computed from window area and wall areas collected separately from BDL files. Statistical analysis was then done to determine average, minimum, maximum, median, first and third quartile, as well as standard deviation to understand the spread of the data over a statewide population of office buildings in California. CEUS expansion weights were used to expand results for individual buildings to limited-statewide estimates. The term 'limited-statewide' as defined in the CEUS Report refers to "the combined electric service areas of the utilities participating in the CEUS: PG&E, SCE, SDG&E and SMUD. Service areas of the Los Angeles Department of Water and Power (LADWP) and a number of small municipal utilities were not part of the project scope."

Note that since a 'space' for this analysis was defined as a HVAC zone in the eQuest models, which may not always correspond to a physical space separated by floor-to-ceiling partitions, or interior walls. However, absent information on interior walls and partitions in these models, the HVAC zone was assumed to be a space.

3.1 Physical Characteristics of Office Spaces in California

In this section, results from the statistical analysis are provided in tables that give the statewide average, minimum, 1st quartile, median, 3rd quartile, maximum and standard deviation for various building and daylit space characteristics. Window and skylight properties were studied in more detail as they are of vital importance to a study on daylighting potential.

Table 2 provides the general results from the statistical analysis of building physical characteristics of office buildings in the CEUS dataset, expanded to the "limited-statewide" population values discussed above. The implications of these findings are discussed below.

Table 2: Statistical Analysis of Physical Characteristics of Office Spaces in CEUS

Building Characteristics	Average	Min.	1st Quartile	Median	3rd Quartile	Max.	Std. Dev.
Building Footprint Area (ft²)	6,491	100	988	1,300	3,600	1,806,948	26,943
Space Area (ft²)	2,804	38	700	1,200	2,460	128,000	5,737
Perimeter Space Depth (ft.)	56	0	20	39.5	72.9	1,017.2	113.9
Wall Width (only walls with windows) (ft.)	63	2	24	42	79	729	59
% Office Floor Area with Plenums	74%	NA	NA	NA	NA	NA	NA
Ceiling Height (ft.)	9.4	7	8	9	10	30	2.37
Ceiling to Window Head Height (ft.)	1.5	0	0	1.2	2.2	21.7	1.7
% Office Floor Area with Overhangs	23%	NA	NA	NA	NA	NA	NA
Overhang Depth (ft.)	3.6	0.4	2	3	5	58.9	2.1
LPD (W/so)	1.28	0.04	0.81	1.15	1.59	7.70	0.67
% Office Area with Existing Photocontrols	< 0.1%	NA	NA	NA	NA	NA	NA

The average 'footprint' of office buildings was 6,491 sf, but three quarters of these offices had a footprint under 3,600 sf. This significant difference between the median and the mean was due to the wide spread of the sample which included a few very large buildings (maximum at 1,806,948 sf).

A 'space area' defined as an HVAC zone in the eQuest models, had an average area of 2,804 sf with a median of 1,200 sf. A 'perimeter space' was defined as an HVAC zone with at least one external wall with windows. 'Perimeter space depth' was calculated as the minimum distance from an external wall with windows, to a wall parallel to it inside the space. In spaces with more than one façade with windows, the perimeter zone depth from each façade was calculated and averaged, weighted by the length of façade. The average perimeter space depth was 56 ft. The surprising minimum value of 0 ft indicates that at least one of the eQuest models was incorrectly modeled with two coincident parallel walls. The analysis also showed that the 'average wall with windows' had a width of 63 ft.

While reviewing the data, it appeared that a significant number of exterior walls didn't have any windows. In order to check if these walls were representing main façades or were rather side walls or 'link' walls between major walls, their widths were analyzed. It turned out that exterior wall with windows were twice as wide as walls without windows, confirming the initial assumption that blank walls were usually smaller, narrower walls of office spaces. The short standard deviation of the sample strengthened this conclusion.

It was also found that 74 percent of the office spaces in California had a plenum. The ceiling height (excluding plenum) was an average of 9.4 ft, with a median of 9 ft. A surprising finding was that a quarter of the spaces had a ceiling height between 7 ft and 8 ft, which seemed low. The distance between the ceiling height and window head height in most spaces was between 0 ft and 2.2 ft, with an average of 1.5 ft, and a very few outliers.

About a quarter of the spaces (23 percent) had at least one window with an overhang. Most of those office spaces had an overhang of between 2 ft to 5 ft, with an average overhang depth of 3.6 ft. The surprisingly high 58.9 ft maximum overhang is most likely an architectural component, modeled as an overhang in eQuest.

On average, the lighting power density was found to be 1.28 W/sf, and most of the office building in the sample had a lighting power density between 0.81 and 1.59 W/sf.

3.1.1 Window Properties

Since daylighting is most affected by window properties, the project team looked at window characteristics in finer detail. Results are presented in table 3 through table 5 below. Table 3 shows the spread of window-to-wall ratios (WWR) across the CEUS dataset for offices.

WWR was calculated using total widow area and total wall area including the plenum walls, This is known as "Gross WWR" as it includes wall area of plenums, such as the wall area as seen from the outside of the building. A "Net WWR" is calculated without including the plenum wall, such as the wall area as seen from the inside of the space.

WWRs in Table 3 are calculated for all office spaces with at least one exterior wall, such as core spaces with only interior walls and basements were not included in the calculations.

Table 3: Statistical Analysis of Window-to-Wall-Ratio of Office Spaces in CEUS -

Building Characteristics	Average	Min.	1st Quartile	Median	3r Quartile	Max.	Std. Dev.
Gross WWR	17%	0%	7%	13%	24%	84%	14%
Net WWR	25%	0%	8%	19%	39%	95%	20%
Gross WWR (only spaces with windows)	24%	0.1%	11%	19%	33%	84%	18%
Net WWR (only spaces with windows)	38%	0.1%	21%	39%	52%	95%	20%

The average gross WWR was 17 percent, and net WWR was 25 percent when accounting for all office space with exterior walls, with and without windows. However, there were a large number of spaces with exterior walls but no windows in the sample. When excluding these non-window spaces, the average gross WWR was 24 percent, and net WWR was 38 percent, with about half the spaces having a net WWR above 39 percent. Most walls had a net WWR between 21 percent and 52 percent.

Table 4: Statistical Analysis of Spaces With One or More Walls with Windows

Office Spaces	No Windows	One Window	Two Windows	Three Windows	Four Windows and More
Number of Office Spaces in CEUS Dataset	855	2336	294	279	276
Statewide Area Percentage (%)	21%	58%	7%	7%	7%
Average Area (sf)	5580	1480	1920	3142	9571

Table 4 shows the number of perimeter spaces with no windows as well as one, two or three windows. Note this analysis was done for sidelighting only, and does not consider skylit spaces. The table also provides percentage and average area of these spaces. The office spaces with no windows formed 21 percent of the spaces. Most office spaces (58 percent of statewide building area) were daylit from one orientation, while 21 percent of statewide building area was daylit from more than one orientation. Thus, in this dataset, about ¼ of building space area with any windows had windows facing more than one direction. For those spaces with windows, it was found that the more orientations from which daylight comes in, the bigger the average space area.

One surprising finding was that Visible Light Transmittance (VLT) was found to be very similar for each orientation, with an average of 0.83 VLT. Upon closer inspection, almost three quarters of the windows were found to be modeled with a 0.9 VLT.

This issue was further investigated and it was found that about three quarters of the spaces in the eQuest models had been assigned a GLASS-TYPE-CODE = "1000" in DOE 2.2, which corresponds to a glass type of "Single Clear", with a VT of 0.90 in the DOE2 Reference Guide. It seemed highly unlikely that three quarters of the spaces in the sample could have this glass type. Single clear glazing results in a very high SHGC and U-factor, which would not pass the California Title 24 glazing performance minimum prescriptive requirements. As a result of this finding, the Itron team is looking into possible causes for why most models were assigned this glass type, and will investigate this finding further.

For this study however, the window VLT properties as found in the database could not be used, as it would result in an overly optimistic appraisal of the daylighting potential. For this project the project team delved further into the survey data, to estimate the window tint, which was then translated to a VLT value and used in the subsequent analysis. This method is described in detail in Section 3.2. The spread of VLT by office type is provided in Table 9 .

Table 5: Sill Height and Head Height

Orientation	Average	Min.	1st Quartile	Median	3r Quartile	Max.	Std. Dev.
Sill Height (ft)	2.1	0.2	0.6	2.2	3.2	7.1	1.4
Head Height (ft)	7.3	2.3	6.8	7.0	7.8	13.2	1.2

Table 5 shows the statistics for sill heights and head heights for the limited statewide office population. Sill height measured 2.1 ft on average, while head height was 7.3 ft on average. Three quarter of the windows had a sill height from 0.6 ft to 3.2 ft, and head height between 6.8 ft and 7.8 ft. Maximum sill height was 7 ft, which likely represented clerestory windows.

The project team also looked at sill and head height variations by orientation, but found that the results more or less consistent across orientations.

3.1.2 Skylight Properties

As with windows, the project team also looked at skylight properties in finer detail. Results are presented in Table 6 and Table 7.

Table 6: Skylight Characteristics in Office Spaces

	Average	Min.	1st Quartile	Median	3r Quartile	Max.	Std. Dev.
% Office Floor Area with Skylights	5.6%	NA	NA	NA	NA	NA	NA
Average SFR in Office Spaces with Skylights	1.1%	0.0%	0.3%	0.8%	1.5%	5.6%	1.0%

Skylights could be found in 5.6 percent of office spaces in California, and these spaces had an average skylight to roof ratio (SFR) of 1.1 percent. Half of them had an SFR below 0.8 percent, which was surprisingly small and the maximum SFR was 5.6 percent. The SFR values seemed low, as most typical SFRs are near the 3 percent range. A possible reason the average SFR was lower than expected is that the definition of a "space" in this analysis was an HVAC zone, which may not always correspond to a physical space separated by floor-to-ceiling partitions. In fact it is highly likely that an HVAC zone has multiple physical spaces contained within it. If skylights are present in one such physical space, which is part of a larger HVAC zone, the SFR calculated at the HVAC zone level will be lower than the true SFR for the space with skylights.

Table 7: Skylight Type by Glass Area and by Zones in Office Spaces

Type of Glass	Percentage of space area with given type of skylight	Percentage of skylight glazing area with given type of skylight
Clear Glass	22%	13%
Clear Plastic	11%	13%
White Glass	0%	0%
White Plastic	55%	71%
Other Glass	11%	1%
Other Plastic	1%	2%

Over half of the spaces with skylights had white plastic skylights (55 percent), and the remaining spaces had either clear glass (22 percent) or clear plastic skylights (11 percent). The other glass and other plastic category make up the remaining 13 percent. White plastic skylights having the largest share of skylight area is in line with our understanding of the most common type of skylight. Almost no white glass skylights (frosted or diffusing) were present in the sample.

3.1.3 Lighting Control Systems

The percent of daylit areas with existing photocontrols was less than 1 percent. This finding is supported by earlier findings such as from HMG filed study of sidelighting and photocontrols (HMG, 2005), that estimated that as of 2004, there were only about 200 sidelit buildings with installed photocontrols in the west coast. This result shows that there is great potential for retrofitting photocontrols in existing office buildings for energy savings in the state.

3.2 CEUS Additional Data Collection

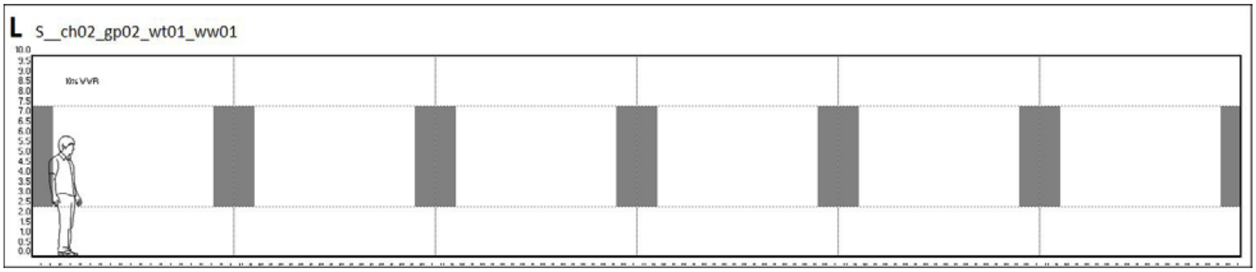
Based on our assessment of the limitations of the CEUS dataset, it was determined that before the dataset could be used on a daylighting potential study, the limitations identified in Section 2.2 needed to be addressed. This required collecting additional information about the 536 office premises in the existing dataset of building physical characteristics in CEUS. This section describes the process employed by the project team to collect and include this additional information.

The team considered many alternatives, and settled on a method in which, with help of the Itron team, much of the missing information could be collected from exterior photographs of the CEUS office buildings, which were taken by the site surveyors. This resulted in additional information describing window layout, exterior obstructions (trees, adjacent buildings, exterior attachments), and window tint. The data collected was included as additional information about each model and as inputs for daylighting simulations.

The following is a list of inputs that were collected from this exercise.

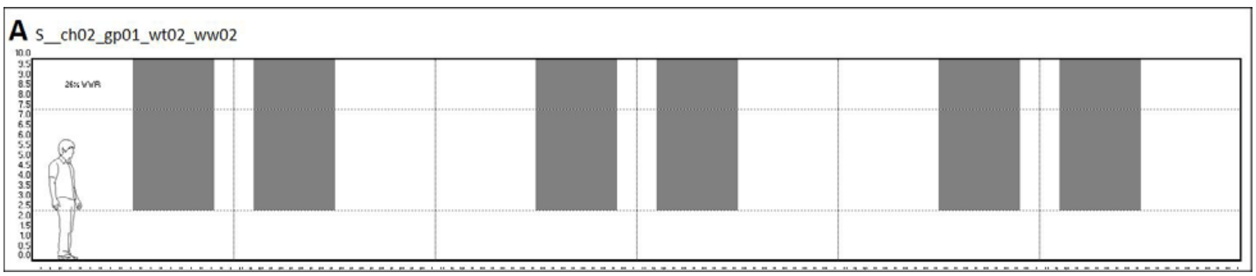
Window Layout: Windows layouts were categorized into four groups; as punched, grouped, strip and curtain wall, as described in Figures 2 through 5.

Figure 2: Example of a Punched Window Façade



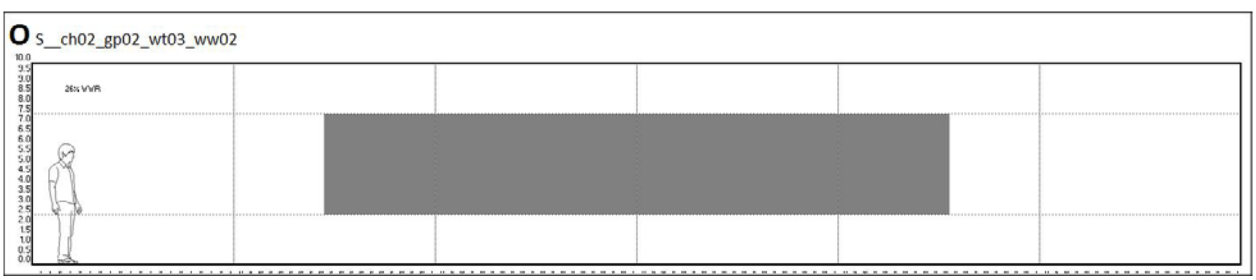
Punched: A façade where windows are separated by a distance greater than the average window width, following a fairly regular pattern.

Figure 3: Example of a Grouped Window Façade



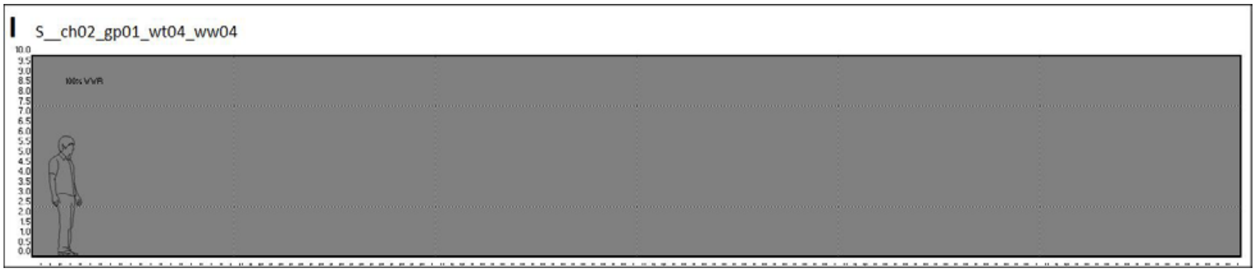
Grouped: A façade where windows are separated by a distance less than the average window width. There may be sets of windows separated by a distance more than the window width, as shown in figure 3.

Figure 4: Example of a Strip Window Façade



Strip: A façade which has a narrow, long window with a raised sill that runs across most of the façade's length.

Figure 5: Example of a Curtain Wall Façade



Curtain Wall: A façade with floor to ceiling windows across most or all of the facade.

b. **Window Tint**: Window tints were categorized into three easily recognizable tints from visual inspection of exterior photographs, as:

Clear: Mostly clear or very light tint, typically VLT 60 percent - 80 percent. Blinds or shades in the interior and their color were easily fairly visible from the photograph.

Medium: Some tint, typically VLT 30 percent - 60 percent. Blinds or shades in the interior were visible, but their color could not be easily determined from the photograph.

Dark: Heave tint, typically VLT 10 percent - 30 percent. Blinds or shades in the interior were not easily visible. This category also included silver or reflective tints.

c. **Exterior Obstructions (Structures):** Exterior obstructions from existing buildings and other built structures were categorized into three general groups, as:

Heavy Urban: High rise buildings/structures that are close to the building's façade, such that they may cast a shadow for many days of the year.

Light Urban: Low rise buildings/structures around the building that are at a distance from the building's façade, such that they cast may cast occasional shadows.

None: No buildings/structures surrounding the building (such as a parking lot), or the adjacent buildings are far enough to not cast a shadow on the building's façade.

d. **Exterior Obstructions (Trees):** Information on tree height, thickness and number of facades with trees was collected using the following inputs:

Tree Height: Entered in terms of number of floors effected (for example, a tree that was tall enough to reach 2nd floor of a building was entered as 2)

Tree Thickness: A value of 10 percent, 30 percent, 50 percent, 70 percent, 90 percent or n/a, which denotes how dense the tree appeared. A tree with 10 percent thickness will proximately allow about 10 percent of the incident sun through, and so on.

Tree Facades: A value between 0- 4, that gives the number of facades of the building with trees.

e. **Exterior Attachments:** The exterior attachments were categorized as screens, awning, and advertisements:

> ***Screens***: Solar or insect screens attached to the exterior of a window
>
> ***Awnings***: Detachable fabric awnings typically over a window or façade
>
> ***Adverts***: Advertisements attached to the exterior of a window which may restrict daylighting

f. **Office Type:** Additional information about the office building and its construction type was also collected. The following 12 categories were used for this classification

One Story

Standalone: Single story standalone structures, typically between 100-3,000 sf

Strip mall: Office spaces that are part of a strip mall, typically between 200-2,000 sf

Garden: Single story office buildings surrounded by landscaping, typically between 2,000-10,000 sf

Warehouse: Warehouse type buildings with high ceilings, and few windows, typically between 5,000-50,000 sf

Other: All single story buildings that don't fit any of the above criteria

Two to Four Story

Residential scale: Buildings that appear to have residential style construction. They may have been built as a residential, and later adapted for use as an office. Typically between 2,000-5,000 sf

Walkup office-tenant (external corridor): Multi- or single- tenant occupied building, typically with wood construction. These buildings typically have circulation corridor on the exterior façade. Typically between 5,000-30,000 sf

Office park-tenant (internal corridor): Multi- or single- tenant occupied building with non-wood construction (steel frame, concrete tilt-up, CMU and so forth). These buildings typically have circulation corridor inside the building. Typically between 10,000-80,000 sf

Low rise headquarters: Custom designed building that is typically owner-occupied. Typically between 10,000-80,000 sf

Other: All 2-4 story buildings that don't fit any of the above criteria

High Rise

Masonry: More than 4 stories high rise building, typically an older vintage, and a load bearing construction using masonry. Typically between 40,000-1,000,000 sf

Other (Modern): More than 4 stories high rise building, using a construction technique other than masonry. Typically between 40,000-1,000,000 sf

3.2.1 Window Characteristics

Once all of the additional data described in the previous section was generated for all office sites surveyed, it was possible to apply site weights, and run statistical analysis on these window and shading characteristics. This section describes the window and shading characteristics as a percent of limited-statewide floor area, categorized by the different office types.

Table 8 provides the distribution of the data on window layout by office type. The percentages in the first column under 'floor area' are relative to total floor area, such as the limited-statewide estimate of all office space in California from CEUS. The percentages for 'window layout' are relative to the total for that line group, in other words each of the four window options add up to 100 percent for the building type category.

Table 8: Window Layout by Office Type

Office type	Floor Area	Window Layout: Punched	Grouped	Strip	Curtain Wall
All Offices		**28%**	**23%**	**22%**	**27%**
All 1 Story	**20%**	52%	17%	6%	25%
All 2-4 Story	**55%**	22%	22%	30%	27%
All High Rise	**24%**	20%	32%	19%	28%

Office type	Floor Area	Window Layout: Punched	Grouped	Strip	Curtain Wall
All Offices		28%	23%	22%	27%
All 1 Story	**20%**	**52%**	**17%**	**6%**	**25%**
1 Story - Garden	1%	87%	0%	13%	0%
1 Story - Other	0%	47%	0%	53%	0%
1 Story - Stand alone	10%	63%	14%	3%	20%
1 Story - Strip mall	6%	29%	23%	7%	41%
1 Story - Warehouse	4%	57%	18%	9%	16%
All 2-4 Story	**55%**	**22%**	**22%**	**30%**	**27%**
2-4 Story - Low rise Headquarters	18%	15%	20%	32%	33%
2-4 Story - Office park-tenant-modern	30%	18%	20%	35%	27%
2-4 Story - Other	1%	13%	50%	10%	27%
2-4 Story - Residential scale	3%	98%	2%	0%	0%
2-4 Story - Walkup office-tenant-wood	3%	35%	51%	3%	11%
All High Rise	**24%**	**20%**	**32%**	**19%**	**28%**
High rise - Masonry	5%	52%	43%	0%	6%
High rise - Other	19%	12%	30%	24%	34%

The most striking observation of the data in Table 8 is that a full 75 percent of office square footage in California was low rise, or under four stories. Given the largely suburban nature of California this is understandable, but stands in contradiction to many people's image of office buildings as existing primarily in high rise downtown buildings.

It was found that the four types of window layouts were essentially evenly distributed when "all offices" are considered. Punched and curtain wall were found in slightly more area with 28 percent and 27 percent floor area, compared to grouped and strip with 23 percent and 22 percent floor area. However when looking at the data by the different office type categories, some trends become discernible. In the "one story office" types, the predominant window layout was 'punched' with more than half (52 percent) of floor area; 'curtain wall' was second with 25 percent of floor area very few strip windows. In the "two to four story offices" type, which is also the most common office type with 55 percent of the floor area, the most prominent window layout was 'strip' and 'curtain wall' with 30 percent and 27 percent of the floor area. In high rise buildings, it was 'grouped' and 'curtain wall' with 32 percent and 28 percent of the floor area.

Table 8 also provides further breakdown of the office types that offer a more nuanced look at how the window layout is distributed among the different office types. In this data the punched window are seen as the most common type for the 'Residential Scale' and the 'Single Story Garden' office type with 98 percent and 87 percent floor area respectively. 'Single Story Standalone', 'Single Story Warehouse' and 'High Rise Masonry' also have punched windows as the predominant façade type. 'Single Story Strip Mall', 'Low Rise Headquarters', and 'High Rise - Other' categories have curtain wall façades in more floor areas than other façade types.

Table 9 provides the distribution of the data on window tint by office type. The tints were categorized into clear, medium and dark as described earlier. It should be noted that data collected here is from visual inspection of exterior photographs, and has limitations which should be kept in mind when using this data. While it was possible to determine tint into three broad categories (clear, medium, dark), other key properties such as low-e, number of panes, and color of glass - neutral versus colored tint could not be determined. While this exercise presents a first attempt at determining key information about window properties, there is a need for much more detailed information.

The percentages are by floor area of office space with total floor area being the limited-statewide estimate of all office space in California from CEUS.

Table 9: Window Tint by Office Type

Office type	Floor Area	VLT Clear	VLT Medium	VLT Dark
All Offices		**42%**	**50%**	**8%**
All 1 Story	**20%**	51%	44%	5%
All 2 Story	**55%**	35%	57%	8%
All High Rise	**24%**	49%	40%	11%

Office type	Floor Area	VLT Clear	VLT Medium	VLT Dark
All Offices		**42%**	**50%**	**8%**
All 1 Story	**20%**	**51%**	**44%**	**5%**
1 Story - Garden	1%	13%	66%	21%
1 Story - Other	0%	56%	44%	0%
1 Story - Stand alone	10%	57%	42%	0%
1 Story - Strip mall	6%	46%	41%	13%
1 Story - Warehouse	4%	51%	49%	0%
All 2-4 Story	**55%**	**35%**	**57%**	**8%**
2-4 Story - Low rise Headquarters	18%	33%	59%	8%
2-4 Story - Office park-tenant-modern	30%	28%	62%	9%
2-4 Story - Other	1%	66%	27%	7%
2-4 Story - Residential scale	3%	84%	16%	0%
2-4 Story - Walkup office-tenant-wood	3%	65%	35%	0%
All High Rise	**24%**	**49%**	**40%**	**11%**
High rise - Masonry	5%	70%	30%	0%
High rise - Other	19%	43%	43%	13%

The data shows that the vast majority of office buildings in California had medium or clear tint windows with 50 percent and 42 percent of the floor area respectively. Dark tint windows were uncommon, found in only 8 percent of office floor area. Further details by office type show a similar distribution of tints.

Clear windows are the most common window tint in the 'High Rise Masonry' type buildings, with 70 percent having clear windows. This was an expected result as most of this type of buildings would be of an older vintage and could be expected to have clear windows. Also, '2-4 Story Residential Scale' office type showed a high percent of floor area (84 percent) with clear window.

Medium tint windows were common in '2-4 Story Office Park with Tenants' with 62 percent of floor area, and 'Low Rise Headquarters' type buildings with 59 percent of floor area.

3.2.2 Exterior Shading Characteristics

This section describes the exterior shading characteristics as percent of limited-statewide floor area, categorized by the different office types. As described earlier, exterior shading information was collected for trees, urban shading, and exterior attachments.

3.2.2.1 Tree Shading

Table 10 shows the results of our analysis on the extent of tree shading by office building type. Data presented here is on the value of three thicknesses that was collected from observations of exterior photographs. The percentages are by floor area of office space. Total floor area is the limited-statewide estimate of all office space in California from CEUS.

Table 10: Tree Shading by Office Type

Office type	Floor Area	Tree Thickness None	10%	20%	30%	50%	70%	90%
All Offices		**40%**	**35%**	**1%**	**19%**	**5%**	**1%**	**0%**
All 1 Story	**20%**	58%	24%	0%	12%	7%	0%	0%
All 2 Story	**55%**	27%	40%	1%	26%	6%	1%	0%
All High Rise	**24%**	56%	34%	0%	9%	2%	0%	0%

Office type	Floor Area	Tree Thickness None	10%	20%	30%	50%	70%	90%
All Offices		**40%**	**35%**	**1%**	**19%**	**5%**	**1%**	**0%**
All 1 Story	**20%**	**58%**	**24%**	**0%**	**12%**	**7%**	**0%**	**0%**
1 Story - Garden	1%	0%	0%	0%	13%	87%	0%	0%
1 Story - Other	0%	3%	44%	0%	0%	53%	0%	0%
1 Story - Stand alone	10%	50%	32%	0%	10%	8%	0%	0%
1 Story - Strip mall	6%	88%	7%	0%	5%	0%	0%	0%
1 Story - Warehouse	4%	39%	34%	0%	26%	0%	0%	0%
All 2-4 Story	**55%**	**27%**	**40%**	**1%**	**26%**	**6%**	**1%**	**0%**
2-4 Story - Low rise Headquarters	18%	23%	38%	1%	33%	4%	0%	0%
2-4 Story - Office park-tenant-modern	30%	22%	48%	1%	24%	4%	2%	0%
2-4 Story - Other	1%	82%	14%	0%	4%	0%	0%	0%
2-4 Story - Residential scale	3%	36%	3%	0%	33%	24%	0%	4%
2-4 Story - Walkup office-tenant-wood	3%	66%	19%	0%	7%	8%	0%	0%
All High Rise	**24%**	**56%**	**34%**	**0%**	**9%**	**2%**	**0%**	**0%**
High rise - Masonry	5%	79%	19%	0%	2%	0%	0%	0%
High rise - Other	19%	50%	38%	0%	11%	2%	0%	0%

The results show that 40 percent of all office area had no shading from trees, while 60 percent some shading. This was a key finding as it showed that a majority of office buildings in California have at least some type of obstruction provided by trees. 35 percent of office area was found to be shaded by trees with low thickness, with trees that block about 10 percent of the incident sun (read as 10 percent tree thickness in the Table). 25 percent of the office area was shaded by medium dense trees, blocking between 20 percent to 50 percent of the incident daylight and solar gains from the sun. Only 1 percent of the office area had very dense tree cover, blocking 70 percent - 90 percent of sun.

The office building types most affected by tree shading were the 'Single Story Garden' type with 87 percent floor area affected by shading from trees that blocked 50 percent of the sun. This was an expected result as the 'Single Story Garden' type buildings were ones with heavy landscaping around them. Also the '2-4 Story Residential Scale' buildings, 'Low Rise

Headquarters' and 'Office Park Tenant' occupied office type had a high proportion of floor area affected by thicker trees (for example, trees blocking more than 30 percent of sun).

3.2.2.2 Urban Obstructions

Table 11 shows the distribution of shading from urban obstructions, such as other buildings, by office building type. The percentages are by floor area of office space. Total floor area is the limited-statewide estimate of all office space in California from CEUS.

Table 11: Urban Shading by Office Type

Office type	Floor Area	Urban Shading None	Urban Shading Light urban	Urban Shading Heavy urban
All Offices		**83%**	**5%**	**11%**
All 1 Story	**20%**	99%	1%	0%
All 2 Story	**55%**	93%	5%	2%
All High Rise	**24%**	49%	9%	41%

Office type	Floor Area	Urban Shading None	Urban Shading Light urban	Urban Shading Heavy urban
All Offices		**83%**	**5%**	**11%**
All 1 Story	**20%**	**99%**	**1%**	**0%**
1 Story - Garden	1%	87%	13%	0%
1 Story - Other	0%	100%	0%	0%
1 Story - Stand alone	10%	100%	0%	0%
1 Story - Strip mall	6%	98%	2%	0%
1 Story - Warehouse	4%	100%	0%	0%
All 2-4 Story	**55%**	**93%**	**5%**	**2%**
2-4 Story - Low rise Headquarters	18%	93%	6%	1%
2-4 Story - Office park-tenant-modern	30%	98%	2%	0%
2-4 Story - Other	1%	96%	4%	0%
2-4 Story - Residential scale	3%	55%	21%	24%
2-4 Story - Walkup office-tenant-wood	3%	78%	7%	15%
All High Rise	**24%**	**49%**	**9%**	**41%**
High rise - Masonry	5%	15%	4%	81%
High rise - Other	19%	59%	11%	31%

A large majority of office areas (83 percent) "saw" little to no obstructions from adjacent structures or urban shading. The same result was seen when looking at the different office types, except high rise buildings, which were mostly located in dense urban downtowns, and hence had a 41 percent of floor area affected by heavy urban shading. Among the high rise, the masonry type buildings are more likely to be in denser urban areas, with the greatest percent floor area in heavy urban shading. The heavy shading experienced by these masonry buildings is certainly somewhat mitigated by their prevalent use of clear glass for windows, discussed in section 3.2.1 above.

3.2.2.3 Exterior Attachments

Table 12 shows the distribution of exterior attachments by office building type. The percentages are by floor area of office space. Total floor area is the limited-statewide estimate of all office space in California from CEUS.

Table 12: Exterior Attachments by Office Type

Office type	Floor Area	Exterior attachment None	Adverts	Awnings	Screens
All Offices		**95%**	**0%**	**2%**	**3%**
All 1 Story	**20%**	92%	1%	4%	3%
All 2 Story	**55%**	95%	0%	2%	3%
All High Rise	**24%**	99%	0%	0%	1%

Office type	Floor Area	Exterior attachment None	Adverts	Awnings	Screens
All Offices		**95%**	**0%**	**2%**	**3%**
All 1 Story	**20%**	**92%**	**1%**	**4%**	**3%**
1 Story - Garden	1%	34%	0%	0%	66%
1 Story - Other	0%	100%	0%	0%	0%
1 Story - Stand alone	10%	92%	3%	4%	2%
1 Story - Strip mall	6%	94%	1%	4%	1%
1 Story - Warehouse	4%	96%	0%	4%	0%
All 2-4 Story	**55%**	**95%**	**0%**	**2%**	**3%**
2-4 Story - Low rise Headquarters	18%	98%	0%	1%	1%
2-4 Story - Office park-tenant-modern	30%	97%	0%	0%	3%
2-4 Story - Other	1%	73%	0%	27%	0%
2-4 Story - Residential scale	3%	92%	0%	0%	8%
2-4 Story - Walkup office-tenant-wood	3%	66%	0%	23%	11%
All High Rise	**24%**	**99%**	**0%**	**0%**	**1%**
High rise - Masonry	5%	100%	0%	0%	0%
High rise - Other	19%	99%	0%	0%	1%

An overwhelming majority of office spaces had no exterior attachments. The only office type where exterior attachment were commonly found was ‘Single Story Garden’, where 66 percent of floor area had screens, and ‘2-4 story Walkup Tenant Occupied’ offices, where 23 percent of floor area had awnings, and 11 percent had screens. However, the 3 percent of advertisements found on “stand alone” offices and the prevalence of awnings for offices in strip mall and warehouse type buildings may have the largest statewide impact, since they represent larger statewide square footage.

CHAPTER 4: Methodology

This section describes the methodology employed to determine the energy savings from daylighting using the CEUS dataset as input to an annual daylighting simulation program. Multiple methodology approaches were discussed by the project team and their merits and disadvantages weighted. Finally, the selected approach using façade-templates was developed and employed in the study.

In order to determine the energy savings potential from daylighting in office buildings, an annual daylighting simulation program would need input from the CEUS dataset. The project team considered multiple approaches of using the CEUS dataset as input to one of two simulation programs - eQuest (DOE2) or Radiance. The approaches varied in complexity of pre- and post- processing of simulation data, as well as in addressing limitations of the CEUS dataset. This section provides four approaches that were considered and discussed their merits.

Approach 1 − Using All CEUS Models in eQuest (DOE2.2)

A simple approach was to use eQuest as the default simulation tool, and run the 536 models with daylighting controls, an option available in eQuest. However this option would have severe limitations for a study on daylighting potential because of DOE2's limited capability to model daylighting. The eQuest (DOE 2.2) daylighting simulation engine uses a split-flux method, which is known to underestimate daylight near a window and overestimate it away from the window (Koti, 2007). Additionally, blinds would have to be specifically modeled in each model, but options would be limited to the options available in the eQuest program. Also daylighting enhancement such as light shelves or advanced light redirecting blinds could not be modeled, as a limitation of the split flux method.

Besides these, the limitations of the CEUS dataset discussed in section 0, would also apply, namely:

1. Ambiguity of space versus HVAC zone definition

2. Lack of furniture

3. Lack of accurate interior surface reflectance

4. Lack of exterior obstructions

5. Lack of detail on façade window grouping

6. Improper VLT for windows

Owing to these limitations, the project team determined that the analysis could not be carried out in eQuest (DOE 2.2), as it would require a significant amount of effort to modify the existing models and would not support analysis of any daylighting improvements

Approach 2 − Using All CEUS Models in Dynamic Radiance

An alternative approach was to convert all the 536 models directly into the geometry needed for Radiance input files (.rad) and then use an annual radiance based daylighting simulation approach such as Dynamic Radiance (Saxena, 2010).

This approach presented some significant technical challenges, and also many crucial limitations. An important first step for this approach would have been to convert the geometric descriptions of spaces in the eQuest models (.inp files) to a geometric description for Radiance (.rad files). This process would have to be automated to be applied at the scale of the CEUS dataset. The project team was able to develop and test a beta version of a java program, which did just that. However, while the program was beta tested for simple rectilinear spaces, it would have taken considerable effort to ensure that non-rectilinear spaces converted without problems. For the CEUS dataset, which comprised of 536 office premises and 3,716 daylit office spaces (from Table 1), this would have required a considerable testing effort.

Another technical challenge would have been running annual simulation using a computation intensive simulation program like Dynamic Radiance. Running simulation on all 3716 office spaces models would have taken a prohibitive amount of simulation time, which, given the time and budget for this project, would not have been practical.

Even if all 3,716 daylit office spaces could be converted to .rad files, and a simulation on each one run using Dynamic Radiance, an analysis resulting from this data would have all of the same limitations described in the first approach, in section 2.2 above. This is because none of the following important characteristics can be derived from the eQuest models: the actual space definition, type of furniture, interior surface reflectance values, presence or absence and type of exterior obstructions, detail on façade window grouping, and actual VLT.

Approach 3 − Using a Subsample of CEUS Model in Dynamic Radiance

A third approach was considered, in which a representative sub-sample of the CEUS dataset could be drawn. Then simulations would be run on only the subset of models, thereby reducing the number of models that would need to be converted into .rad files. With a smaller subset, it would be possible to take the time required to address the limitations of the eQuest models described in Section 2.2 on 2.2.Note on Limitations of the CEUS Dataset for these subset models.

It is important to note that CEUS's dataset is already a small sample of the actual office building population in California. This representative sample was carefully chosen, using annual electric energy consumption as the primary sampling variable.

A further stratification of this sample for a daylighting potential study would mean that in addition to the four CEUS strata, these office buildings would be further classified based on physical characteristics affecting their daylighting. Eight physical characteristics were identified that were deemed minimally important to define the new daylighting strata namely, window-to-wall ratio, orientation, visible light transmittance, ceiling height, difference between ceiling and window head heights, skylight, overhangs, external shading.

On working out the minimum number of models in the new sub-sample, it was determined that to represent each stratum (the original four from CEUS and the additional eight for daylighting) the sub-sample would be almost as large as the initial sample and save little or no time. It was concluded that this approach was not worth the additional effort or recalculating expansion weights, since the result was a very small decrease in the number of simulations runs compared to running all models.

The project team considered modifying our sub-sampling approach by suppressing some CEUS strata, however that resulted in increased inaccuracies in the energy savings estimates, and further imprecision introduced by reallocating expansion weights.

Final Methodology: Approach 4 − Use of Façade Templates in Dynamic Radiance

An alternate approach to the three approaches described above was to develop a set of façade templates - generic representations of various façade designs, attached to a simple rectangular space, which could be modeled in Dynamic Radiance. Annual illuminance results from these templates could then be mapped to every exterior façade in the 536 CEUS office models. The mapping process would involve modifying the lighting schedule for a space based on illuminance data for each façade template. The templates would provide illuminance data per façade to drive photocontrols, thus enabling calculation of lighting energy savings. The variations in façade design would incorporate different window layouts, window properties and other façade characteristics such as overhangs, ceiling heights and so forth.

This approach implies that each of the 6,159 façades in the CEUS models (from Table 1), could be mapped to a more or less representative façade template. In other words, a large number of templates capturing multiple variations in façade designs would enable a more accurate mapping to exterior walls. Since these façade templates are fairly simple generic spaces that could be run in less time using Dynamic Radiance than a direct simulation of each space in the CEUS dataset, as proposed in Approach 2, this allowed us to develop a sufficiently large number of templates for this approach.

A great advantage of this approach was that since the Dynamic Radiance simulations were done for generic façade templates, which could be designed based on information about the exterior facades of each CEUS model, the limitations inherent in the CEUS eQuest models could be addressed in the design of the façade templates. For example window layouts could be designed in each façade template, instead of modifying each CEUS eQuest model. Similarly, this approach addressed most of the limitations described in section 2.2, as explained below.

1. Ambiguity of space versus HVAC zone definition: Templates were designed as either open office, private office or small office, and assigned by façade, independent of HVAC zone depth or dimension.

2. Lack of furniture: Furniture was modeled and added to the template spaces with three variations: 30″, 45″ or 60″ high partitions.

3. Lack of accurate interior surface reflectance: Typical surface reflectance values were used in the façade templates.

4. Lack of exterior obstructions: The level of urban and tree shade for each office model, 'high', 'medium' or 'no', exterior shading was applied to the façade templates based on site survey data.

5. Lack of detail on façade window grouping: Different façade templates were created for different window groupings and layouts and then assigned to the appropriate buildings.

6. Improper VLT for windows: Façade templates were created with three window VLTs: 10 percent, 40 percent and 70 percent. Based on window tint information for each office model, the façade with the most appropriate VLT was applied.

Besides these advantages, using the façade template approach it was also possible to quantify energy savings from daylighting improvements by modifying the template models. Improvements include adding light shelves, increasing interior reflectance values, and reducing furniture heights. Compared to individually adding these improvements on a set of radiance files converted from eQuest models, as in Approach 3 described above, this was much easier with templates as the process could be automated.

Façade templates and how they were constructed are discussed in Section 4.1. Although the templates represent daylight from only one exterior wall, they could be very easily applied to CEUS models with spaces that have more than one exterior façade. These spaces would get more than one façade template mapped to it - one for each exterior wall. Lighting energy savings from daylighting would be calculated for each façade separately and then summed up proportionally for the space.

After considering all four approaches, the team determined that the façade templates approach represented the most appropriate way to study the daylighting potential of office buildings in the CEUS dataset.

4.1 Façade Template Development

This section describes the process employed to develop façade templates, which form the basis of the final methodology for the study, and how the templates were mapped back to the exterior facades in the CEUS dataset.

4.1.1 Templates Development Process

The challenge in designing the façade templates was to develop them such that they sufficiently capture the variety in façade designs found in the CEUS dataset. To design the façade templates, the project team first identified eleven variables that were determined as those most likely to affect daylighting in a significant way. Statistical information about each of these variables was then collected from the CEUS dataset to get an understanding of how widely each variable varied in the dataset. The statistical analysis, described in Section 3, provided the basis for this process. The eleven variables identified (and number of options considered) were:

1. Orientation (8)
2. Window-to-wall ratio (4)
3. Ceiling height (2)
4. Difference between ceiling and window head heights (2)
5. Window layout (4)
6. Visible Light Transmittance (3)
7. Skylights (2)
8. External shading (3)
9. Overhangs (2)
10. Office Size (2)
11. Private or open office layout (2)

4.1.1.1 Office Type Templates

Out of these, information for statistical analysis was available for all except 'Office Size' and 'Private or Open Office Layout' from the CEUS dataset. An office space could be a large office with a wide façade, where perpendicular walls to the external façade were space far apart, or a small office with a narrow façade, where perpendicular walls to the external façade were space closer. Both these types of office spaces would provide a very different daylit environment which was important to capture in the study. The information in the CEUS dataset did not include information on location of interior walls, nor did it include information about if the office spaces had a private or open office layout.

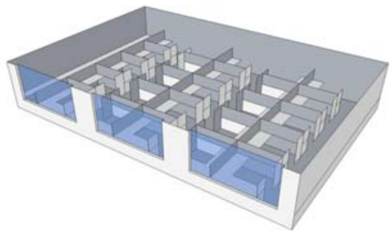
To get over this issue, the project team identified the 'activity type' of each space. This was captured in the on-site survey forms, and provided a description of what that space was used for. Based on the description of activity type, the project team then assigned one of three office type templates:

1. **A large open office**: A 60ft wide x 40ft deep template space with typical office furniture layout found in large open offices as shown in Figure 6.

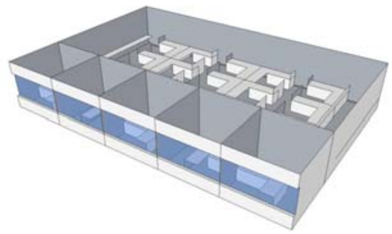
2. **A large private office:** A 60ft wide x 40ft deep template space with 12ft x 12ft private offices adjacent to the exterior façade, with typical office furniture layout found in private offices in them, and typical office furniture layout found in large open offices in the rest of the space as shown in figure 6.

3. **A small office:** A 20ft wide x 40ft deep template space with typical office furniture layout found in small offices as shown in figure 6.

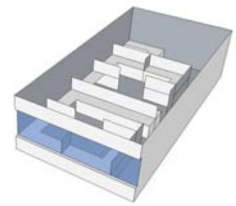
Figure 6: Office Type Templates



Large Open Office Layout



Large Private Office Layout



Small Office Layout

The three office type templates were assigned to spaces with specific activity types as described in Table 13 below, based on the project team's professional reasoning of typical layouts found in various activity types.

Table 13: Space Activity Type and Office Size Template Allocation

Space Activity Type	Occurrence	Office type template assigned
Office (General)	50.81%	Large Open
Office (Open Plan)	10.38%	Large Open
Office	10.05%	Large Private
Laboratory, Medical	2.83%	Large Open
Corridor	2.30%	Large Open
Other Use	2.30%	Large Private
Office (Executive/Private)	2.15%	Large Private
Bank / Financial Institution	1.88%	Large Open
Medical and Clinical Care	1.85%	Small
Conference Room	1.29%	Small
Dining Area	1.06%	Large Open
Lobby (Reception/Waiting)	0.78%	Large Open
Courtrooms	0.59%	Large Open
Lobby (Main Entry / Assembly)	0.54%	Large Open
Exercising Center / Gym	0.45%	Large Open
Classroom / Lecture	0.41%	Small
Convention / Meeting Center	0.40%	Large Open
Library	0.21%	Large Open
Lobby	0.21%	Large Open

4.1.1.2 Variables with Continuous Data Range

For those variables that had a continuous data range available from the CEUS dataset, namely 'Window-to-wall-ratio', 'Ceiling height' and 'Ceiling-head height differential' the process of developing template design parameters was based on the statistical analysis, described in Section 0. First, 'natural breaks' in the distribution of values for each of these variables were identified. A 'natural break' is a point on the range of values for a given variable that identifies a marked separation of population above and below that point. Next, based on these natural breaks, 'bins' were identified that represents a more or less equal number of façades in the CEUS dataset. The wider the distribution of values (the bigger the standard deviation) for a variable and bigger the perceived impact of the variable, the higher the number of bins identified. An appropriate point within the range of each bin was then used to form design parameters for the façade template designs.

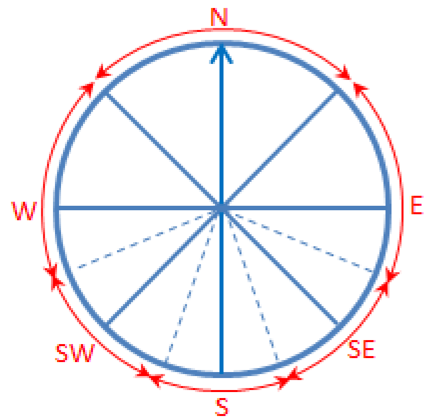
For example, four bins were identified for window-to-wall ratio (WWR) as values, which ranged fairly continuously from 0 percent to 96 percent. In this case, the four bins were represented by the middle value of the four quartiles. On the other hand, only two bins were defined for ceiling height as most of the space had similar ceiling heights, centering around the values of 8ft and 10ft.

4.1.1.3 Variables with Categorized Data Range

For those variables where data was not available as a continuous range, but in specific categories, the categories became the bins. These variables included 'Orientation', 'Window Layouts', 'Window VLT', 'Skylights', 'Shading', 'Overhang' and 'Office Size'. Their bins and template design parameters are provided in Table 15.

Orientation: The CEUS dataset recorded façade orientations in cardinal and ordinal (or intercardinal) directions, such as N, S, E, W, NE, SE, SW, and NW. The project team modified these categories to create bins for this study as shown in figure 7 below. The modified categories provide a finer resolution for South, Southwest and Southeast orientations, as they are the orientations that provide most sensitivity for daylighting.

Figure 7: Orientation Categories



Window Layouts: Based on the additional data collected by the project team, discussed in Section 3.1.1, four categories of window layouts were identified for each building in the CEUS dataset, namely punched, grouped, strip and curtain wall, which were used as the bins for this variable.

Window VLT: Based on additional data collected by the project team, discussed in Section 3.1.1, information on Window VLT was collected as clear, medium or dark tint. These three categories were used as the bins for this variable. Template design parameters were chosen as mid points for the range of VLTs for each category.

Skylights: The project team's analysis of the CEUS dataset found that the skylit spaces in the dataset did not have a statistically significant range of skylight-to-floor area ratios (SFR). Also, very few spaces had SFR less than 1 percent. It was hence decided to use 1 percent SFR as a break to define two bins - a no skylights bin with SFR < 1 percent, and a skylights bin with SRF >=1 percent. The template design parameters were chosen based on the mean SFR and VLT from the statistical analysis.

Shading: Based on additional data collected by the project team, discussed in Section 3.1.3, information on external shading from trees, shading from urban structures like other buildings, and self-shading - created by a wall on one side or both sides of a façade due to the geometry of the building the space was in, was processed into three categories - none, medium and heavy, based on the methodology presented in Table 14.

Table 14: Shading Code Table

Step 1: First a code of A, B or C was first determined for each space based on Table 14.

Code	Self-Shading	Tree Shading	Urban Shading
A	No	No (0-10% tree obstruction)	No
B	One orientation	Low (20-30% tree obstruction)	Light
C	Two orientations	High (40-100% tree obstruction)	Heavy

Step 2: A space was then categorized as having shading - none, medium or heavy, based on the following rule set:

- Combination 2 A or more : none

- Combination 2 C or more : heavy

- Other combinations : medium

Section 4.1.6 discusses how the three categories (none, medium and heavy) were modeled in the simulations.

Overhang: Based on information from the CEUS dataset, if a façade had overhangs, it was assigned a template with a median overhang size.

Office Size: As discussed earlier in this section, office spaces were categories as large open office, large private office and small office based on activity types given in Table 13. The three categories were used as the bins for this category.

Table 15 lists the bins and the template design parameters identified for each variable in the study.

Table 15: Façade Template Variables and Breaks for Each Variable

Variable	Bins	Template Design Parameter	Template Nomenclature
Orientation	315º to 45º	True North	N
	45.0º to 112.5 º	True East	E
	112.5º to 157.5º	True South East	SE
	157.5º to 202.5º	True South	S
	202.5º to 247.5º	True South West	SW
	247.5º to 315.0º	True West	W
Net WWR	WWR<=13%	10%	ww01
	13%<WWR<=44%	26%	ww02
	44%<WWR<=90%	52%	ww03
	WWR>90%	96%	ww04
Ceiling Height	x<=9	8	ch01
	x>9	10	ch02
Ceiling-Head height differential	x<=1.5	0	gp01
	x>1.5	2	gp02
Window Layouts	Punched	Punched	wt01
	Grouped	Grouped	wt02
	Strip	Strip	wt03
	Curtain Wall	Curtain Wall	wt04
Window VLT	x<=20	10	vt01
	20<x<=60	40	vt02
	x>60	70	vt03
Skylights	x<1.0% SFR	0% SFR	sk01
	x>=1.0% SFR	1.1% SFR; Skylight VLT:0.74	sk02
Shading	No	No	sh01
	Light	Shading wall at 25 degree profile angle	sh02
	Heavy	1 Ceiling height deep vertical fin from middle of façade and wall parallel to facade	sh03

Variable	Bins	Template Design Parameter	Template Nomenclature
Overhang	No	No overhang	oh01
	Yes	3 ft overhang	oh02
Office Size	Small office	20ft x 40ft, Private office layout	os01
	Large office private	60ft x 40ft, Private office layout	os02
	Large office open space	60ft x 40ft, Open office layout	os03

A comprehensive list of façade templates was first created using the design parameters identified in Table 15. This total list was determined as follows:

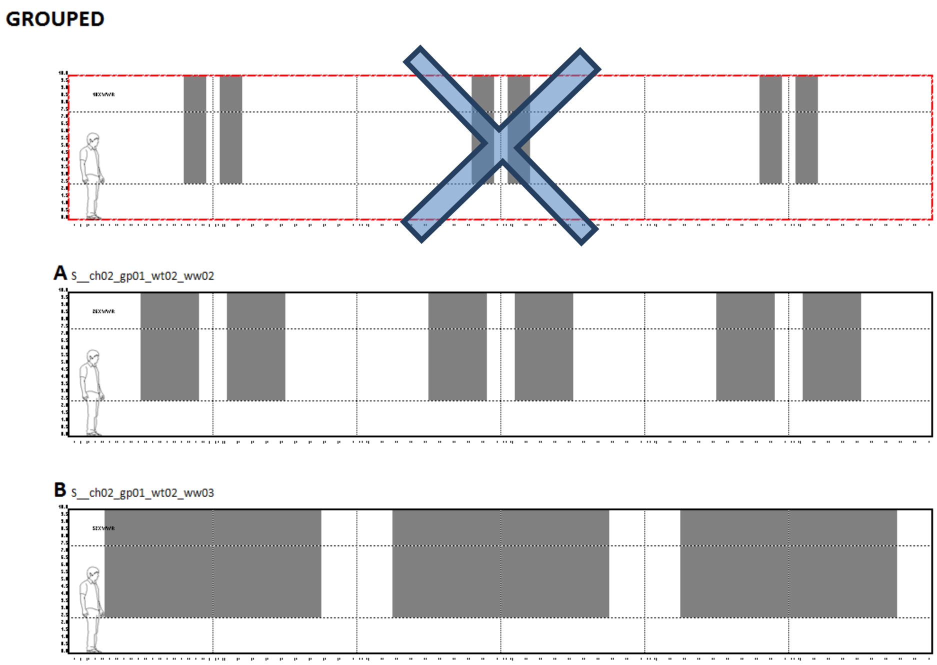
[4 WWRs * 2 Ceiling Hts * 2 Ceiling-Head height differential * 4 Window Layouts] * 1 VLT * 2 Skylights * 3 Shadings * 2 Overhangs * 3 Office Sizes * 6 Orientations = 13,824 façade templates.

Note that VLT was not a template characteristic; simulation runs for 70 percent VLT glazing were proportionately scaled to produce results for 10 percent and 40 percent VLT glazing.

This very large number of templates however represents an exhaustive list of all possible combination of each variable. Each template was then mapped to the CEUS data set, and eliminated those templates that either did not occur, or occurred in less than 100 facades, in the CEUS dataset. This process decreased the number of required façade templates significantly. If a combination of variables in a template did not occur in the CEUS dataset, it was eliminated; if it occurred less than 100 times, it was substituted with a template that occurred more than 100 times and which was the most similar to that template. An order of preferences of variables was used to do these substitutions.

The 64 possible combinations of WWRs, Ceiling Hts., Ceiling-Head height differential and Window Layouts identified with square brackets '[ ]' in the above equation, were reduced to 24 using the elimination and substitution process. These 24 façade templates (identified as A through X) are given in APPENDIX A. Figure 8 shows a set of grouped window facades with 10 percent, 26 percent and 52 percent WWR. The facade in the figure with the red dotted outline and a "X" mark was eliminated or substituted due to low or no representative population.

Figure 8: Grouped Windows: 10ft Ceiling HT, 0ftHhead − Ceiling HT, 10%-26%-52% WWRs



Once elimination and substitutions were done for the entire set, the total number of façade templates reduced to a total of only 861 façade templates. Scaling the simulation results for 3 VLTs for each template, created a final count of 2,583 façade template results.

4.1.2 Façade Template Mapping

In order to accomplish the elimination and substitution process to generate the final façade templates list, each external wall in the CEUS models had to be mapped to a façade template. This mapping created a lookup table for every external wall in the CEUS dataset with windows and the template that it was mapped too.

The CEUS office buildings dataset consists of a total of 7,979 exterior façades (from Table 1). However not all of these exterior façades are required for the façade mapping exercise. Of these 1,156 exterior façades have no windows, and are thus blank (or blind) facades, and 664 facades, or 8 percent, belong to spaces with activity type not suited for daylighting. This leaves 6,159 exterior façades with windows.

Each exterior facade belongs to a space, which has a space activity type assigned to it. The space activity type information was collected during on-site surveys and used in this project to assign small and large office layouts (Table 13). On critically reviewing the activity types, the project team found that there were certain activity types such as storage, restrooms, locker rooms, that may not be suited to photocontrols. These spaces were eliminated from our sample. APPENDIX B provides a table of space activity types and the project team decision to kept or eliminate that space activity type from the study. All eliminated space activity types account for a total of 9.5 percent of limited-statewide floor area. Without counting eliminated activity type spaces, that left 6,159 exterior walls with windows and relevant activity types. These were mapped to one of the total 2,583 façade templates developed as described in Section 4.1.

4.1.3 Façade Template Modeling and Daylighting Simulation

Once façade templates and their mapping process was developed, the team developed Radiance files for each template space, and ran annual daylighting simulations to assess their daylighting energy savings potential. This section describes the process undertaken to model the façade template radiance files and to run annual daylighting simulation using Radiance.

4.1.3.1 Climate Zones

Each of the 24 templates (A through X) described in APPENDIX A were created as a .rad files with a 60ft x 40ft or a 20ft x 40ft space attached to a 60ft or 20ft exterior facade. A set of java programs converted these 24 base templates into 5,184 templates by adding 3 cases of exterior shading, 2 cases of overhangs, 6 cases of orientations, 3 cases of office size and 2 cases of skylights, through an automated process. Dynamic Radiance simulations were only run on 861 of these 5,184 templates as discussed in Section 4.1.1.

Four climate zones were chosen as representative of the variations in climate (related to daylighting) found across the state of California. The climate zones chosen were: CZ2, CZ12, CZ13 and CZ6. Table 16 shows the four climate zones and which CEUS weather files were mapped to these for CZ weather files.

A total of 3,444 (861 templates * 4 climate zones) simulation runs were run to develop a base case result of energy savings from adding photocontrols. Additional simulation runs were done to quantify savings from daylighting improvements.

Table 16: Climate Zones for Analysis

Chosen Climate Zone	Climate Type	Utility Territory	Representative City	Map to CEUS weather files
CZ2	North coastal (Heating Dominated)	PG&E	Santa Rosa	Santa Rosa Monterey Miramar Oakland San Francisco
CZ12	Central Valley (Intermediate)	SMUD	Sacramento	Riverside Red Bluff Sacramento Bishop
CZ13	Sunny inland (Cooling Dominated)	PG&E	Fresno	Fresno Barstow-Daggett Blythe
CZ6	South coastal (Mild)	SCE	Los Angeles	San Jose Santa Maria Long Beach San Diego Burbank Los Angeles

4.1.3.2 Window Blinds Modeling and Operation

Windows blinds or shades (hereafter, referred to as 'blinds'), and their operation play a critical role in determining the quantity of daylight in a space. An accompanying report to this report on the Daylight Metrics (Heschong, 2011) describes findings that show that operable blinds or shades were found in 84 percent of all the spaces studied. The report also shows that accurate modeling of blinds in a daylighting simulation is essential to achieving reasonable results.

Blinds Modeling. To model window blinds accurately for the annual daylighting simulations, the project team used the WINDOW 6 software from Lawrence Berkeley National Laboratory (LBNL) to generate a model of typical mini-blinds or venetian blinds. The Window 6 software generates a three-dimensional descriptive matrix of values of blinds transmittance in all directions, known as a Bi-Direction Scatter Distribution Function (BSDF). This BSDF is subsequently used in the Radiance simulations using the Dynamic Radiance approach (Saxena, 2010). Further details and information about BSDFs and the Dynamic Radiance approach are given in Appendix D and E.

Blinds Operation. The Daylight Metric study also found from both site interviews and survey data, there was strong evidence that the occupants were actively using the blinds to modulate daylight and sun penetration in their spaces. Thus, it was determined that modeling blinds operation, hourly by orientation, was necessary to generate annual daylight conditions in the study spaces.

This study used the same standardized blinds operation trigger developed for the Daylight metrics study, based on potential sunlight into the space as the threshold for closing the blinds in the simulation. Blinds for any window group, grouped by orientation and shading characteristics, were closed for each hour when 2 percent or more of the sensors in the space were found to be in direct sunlight. Direct sunlight was defined as greater than 1000 lux of direct sunlight, excluding contributions from the sky or reflected sunlight—in other words, the difference between a sun patch and the ambient light level in the adjacent shadow. While this is an aggressive operation schedule, it was judged to be the minimum condition likely to be employed by space occupants.

4.1.4 Modeling Daylighting Improvements

Daylighting improvements are physical changes that can be made to a space to enhance daylighting energy savings. To model daylighting improvements, four measures were chosen as listed below, which were applied to the base case, or the "as-is" case. These were chosen as they can be fairly easily incorporated in existing office spaces, and do not require a change in the building envelope or structure. Hence measures such as changing window glazing, or increasing window head height or ceiling height were not included. The four measures resulted in five additional runs for each space: 1. Improved surface reflectance 2. 45" high furniture partitions 3. 30" high furniture partitions 4.light shelves 5. Split blinds.

1. Interior Reflectance: A standard reflectance in the as-is case was 20/50/70, meaning 20 percent reflectance for floor, 50 percent for walls and 70 percent for ceilings. In the improved case, this is increased to 30/60/85 indicating 30 percent reflectance for floor, 60 percent for walls and 85 percent for ceilings. These values are slightly lower than IES recommended values for standard interior reflectance, chosen to provide conservatism in the savings calculations.

2. Lower high furniture: Standard furniture was modeled as 60" high partitions, for each type of layout (large open, large private and small). Two improved cases were simulated: one with 45" high furniture, and one with 30" high furniture. In addition to the reduced furniture height, in the large private office layout, the walls for the private office, parallel to the exterior façade was changed from opaque to glazed. Since reduced furniture height represent improvements made to enhance daylighting, the change from opaque to glazed wall for the private office was made to reflect a conscious decision made by the building owner to increase daylighting in the space.

Figure 9: Furniture Layouts for Small Office Layout

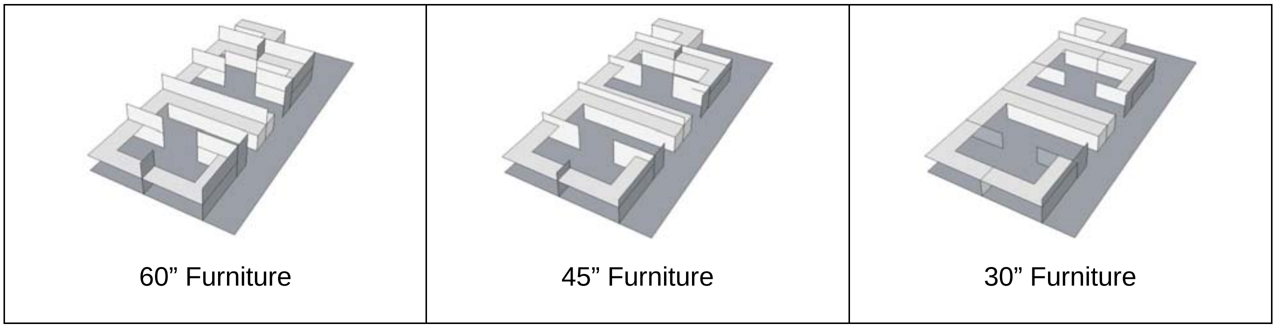


Figure 10: Furniture Layouts for Large Open Office Layout

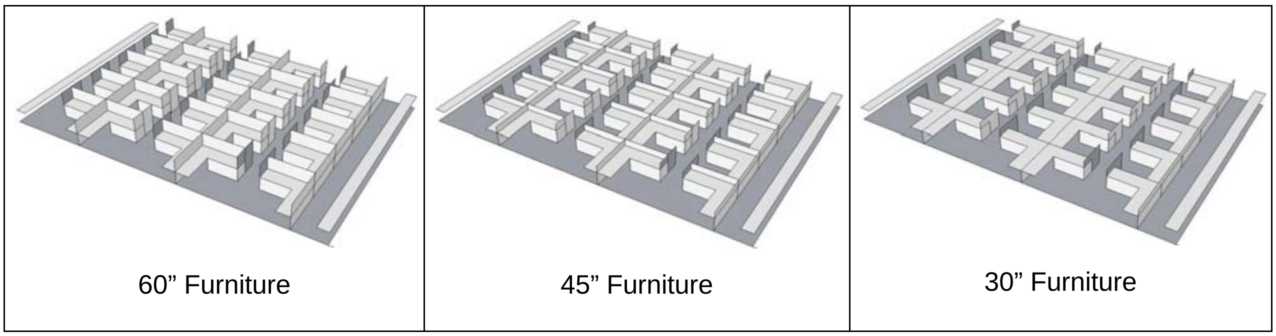
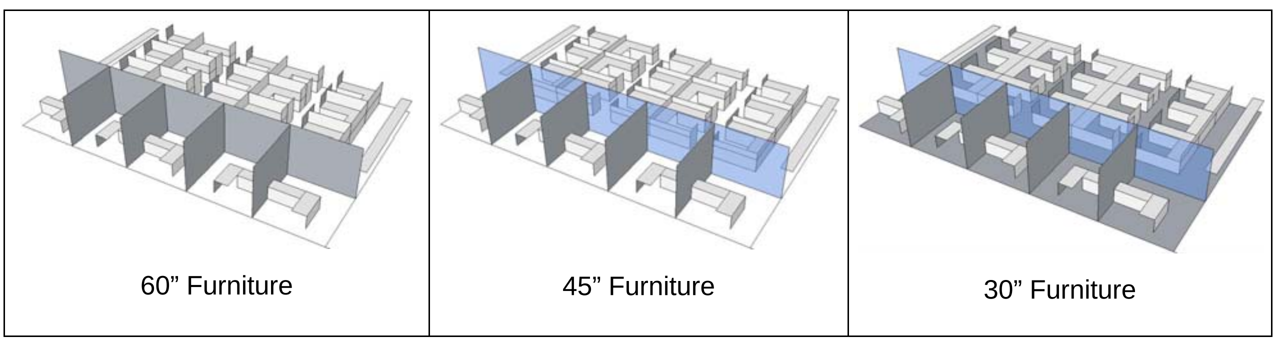


Figure 11: Furniture Layouts for Large Private Office Layout



3. Light Shelves: The as-is cases were not modeled with light shelves. The improved cases with light shelves were modeled with a light shelf located 8′ above the floor. The light shelf was 3 feet deep and continuous across the width of the exterior wall in the template. Light shelves were only included in a template model if the following conditions were met:

1. **Template was South, South-East or South-West facing**. Light shelves provide very little improvement in East or West due to low sun angles, and are detrimental to daylighting on the North.

2. **Ceiling height was 10′ ceiling.** Lower ceiling heights (8 feet) could not be modeled with a light shelf, as the light shelf was modeled to be 8 ft from the floor.

3. **Ceiling Ht.** - Head Ht. differential was 0 ft. (window extends to the top of the ceiling). When a window does not extend to the ceiling, a light shelf at 8 ft. would leave very little clerestory window to make a significant daylighting contribution.

Blinds were placed on both the clerestory and view windows and were operated separately. The blinds were modeled and operated the same way as blinds normally were for the as-is case, except that when blinds were triggered, the view window blinds were lowered first. If, after closing the view-window blinds, the percent of the sensors in direct sun criteria was not met, the clerestory blinds were also closed. Once the condition for the blinds trigger was past, the clerestory and view blinds were retracted.

4. Advanced Blinds: In the as-is case, standard mini-blinds were modeled, using a BSDF file from WINDOW 6 as explained in Section 4.1.3.2 above. These were 1" blinds with a spacing of 0.75" colored off-white. The blinds were operated using the direct sun trigger explained earlier. When the mini-blinds are lowered to block direct sun, they cover the window from head to sill and are closed at 60 degrees with the "bottom" surface of the mini-blinds facing into the interior space.

Initially, two of the categories of advanced blinds - advanced inverted blinds, and split blinds, were modeled, but both were dropped from the final analysis. The split blinds were modeled with a static angled venetian blind on the clerestory, angled to block direct sun, and an operable venetian blind on the view window. However this was also dropped because the correct base case for comparison, blinds always closed, was not available. The decision to drop the advanced inverted blinds was taken because the project team was limited to using BSDFs from the WINDOW 6 software, which currently does not have the built-in capability to model inverted blinds. This limitation has been communicated to the Windows and Daylighting Group at LBNL, which is responsible for development of the WINDOW 6 software. Further improvements are expected to be available with advanced blinds in the market, however more refinement is needed in optical modeling and operation assumptions to be able to correctly predict their impacts.

4.1.5 Radiance Parameters

Sensors were laid out in a grid across the entire space. Sensors were located 31 inches above the floor -- one inch above the desktops in the models. Sensors were spaced two feet apart starting one foot from each wall. The large offices contained 600 sensors and the small offices contained 200 sensors. Walls and partitions were positioned between sensors to avoid covering a sensor.

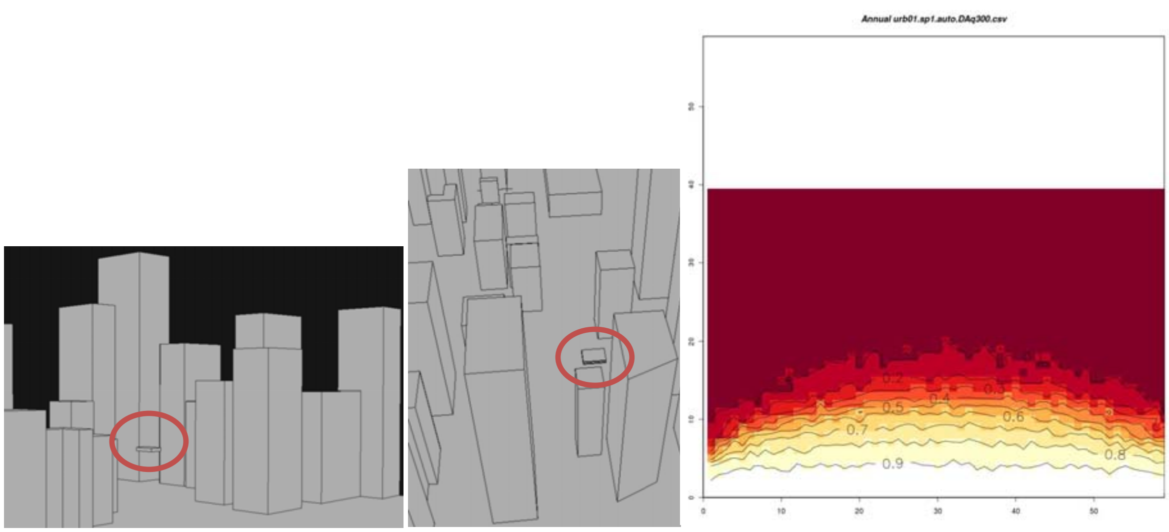
The same sensor grids were used for work-plane illuminance and sun penetration results. This methodology is consistent with the Daylight Metrics work published in a separate report as part of this PIER LRP-2 project. Other Radiance parameters used in the analysis are explained in the Appendices of the Daylight Metrics report.

4.1.6 Modeling Exterior Shading

Exterior shading was categorized as none, light, or heavy shading as described in Section 4.1.1. A short modeling exercise was undertaken to determine an equivalent exterior shade to a light and heavy urban shading.

In this exercise, an example daylight autonomy plot was created for a 40 foot deep by 60 foot wide space located in a dense urban environment as shown in figure 12. The associated Daylight Autonomy plot shown in figure 12 is a metric for sufficiency of daylighting in a space, defined as the percent of occupied hours that received sufficient daylight (defined here as 300 lux). More on daylight autonomy and DA plots can be found in the accompanying PIER report on Daylight Metrics

Figure 12: Daylight Autonomy Plot for Example Space Modeled in Heavy Urban Shading



Several exterior obstruction designs were then tried out to determine the one that gave a daylight autonomy plot similar to that in figure 12. These included courtyards with a wall forming a 24˚ profile angles for an interior view point, fins jutting out of the building, and fins jutting out of the building with an exterior wall parallel to the windows at the end of the fins. The models and associated results are presented in APPENDIX C.

The team found that shading model b3 consisting of a vertical fin 1 ceiling height deep, from the middle of the façade going outwards, and a parallel wall the length of the façade, shown in figure 13 had a daylight autonomy plot that matched closest to the one for the dense urban shading. Shading model c1 shown in figure 14 was chosen as an approximation of light shading. This consisted of a shading wall that made a 25 degree profile angle from the middle of the façade window. The c1 model was consistent with a description of low-rise obstruction as developed by Carmody et al. (Carmody, 2004).

Figure 13: Shading Model b3

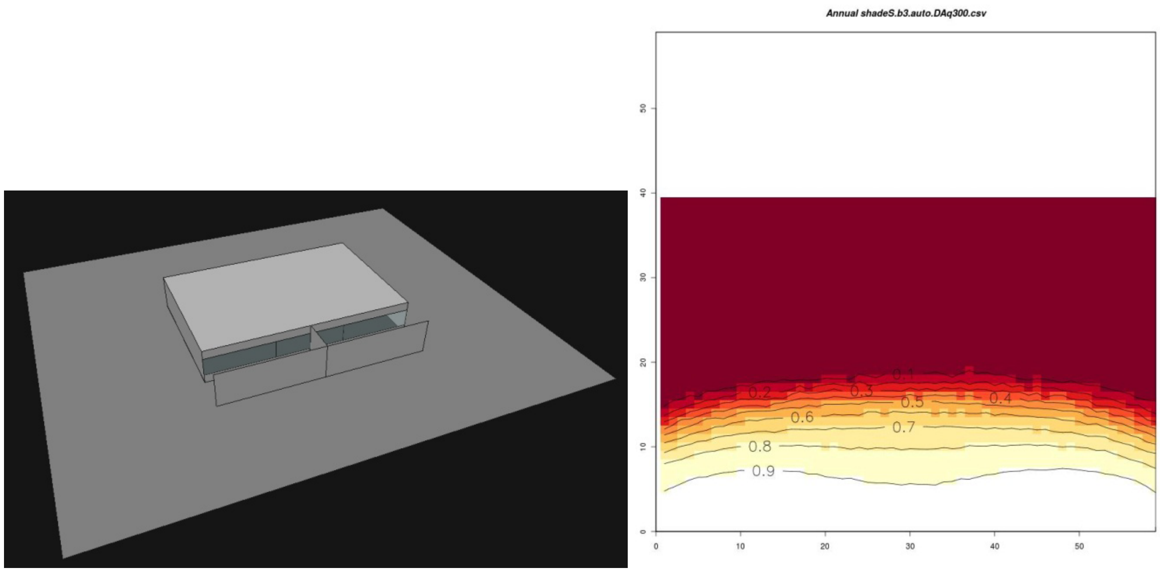
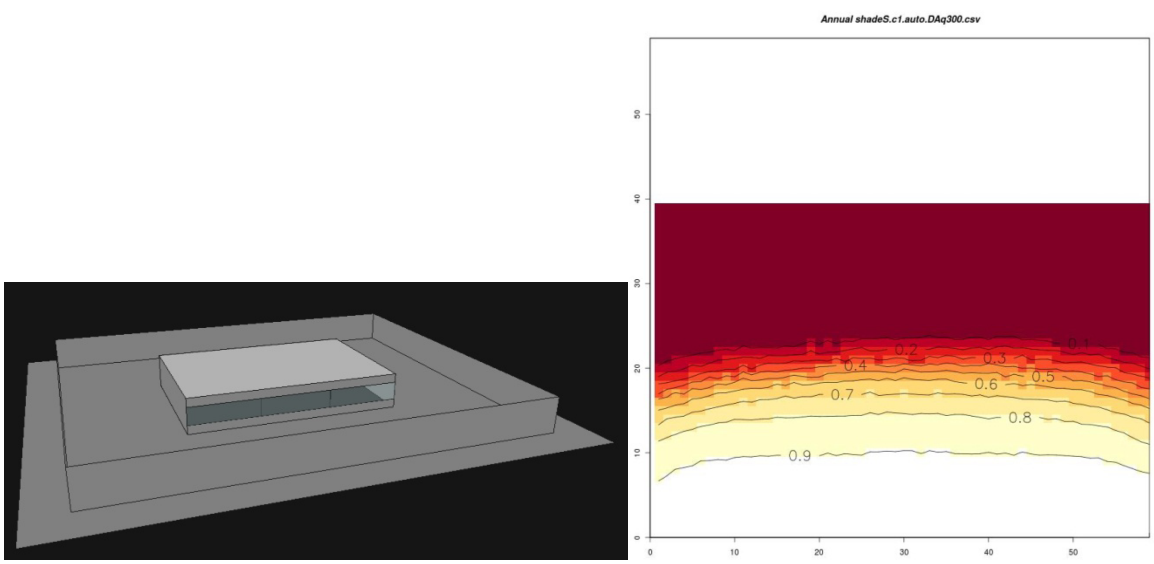


Figure 14: Shading Model c1



4.2 Lighting Schedule Development

This section describes the process of generating a 'modified lighting schedule' the office spaces in the CEUS dataset, based on daylight availability and an assumption that photocontrols are installed in all spaces. A modified lighting schedule is an hourly, annual schedule of lighting energy use (8,760 values) that a space would have if photocontrols were present that dimmed or turned off electric lighting in response daylight in the 'daylit areas' of that space.

For each space in the CEUS dataset, a base case lighting schedule was available from the eQuest models. Also given was the lighting power density for each space. A modified lighting schedule was generated for each space separately. The process involved two steps:

1. Daylight availability in each space was determined using data about daylight illuminance from the façade templates approach. Based the daylight available for each hour, percent electric lighting load was determined. For a 2-level switching system this was 100 percent - 50 percent - 0 percent, whereas for a 20 percent dimming system, it was a value between 100 percent - 35.1 percent.
2. This value was then applied to the base case lighting schedule to create a modified lighting schedule.

The project team devised a method of taking simulation results from the template-spaces, which were either large, 60ft x 40ft, or small, 20ft x 40ft, generic office spaces with various façade designs, and applying them appropriately to the spaces in the 536 office premises in the CEUS dataset. This method is described in this section.

4.2.1 Daylit Areas

The first step to developing a modified lighting schedule was to determine what proportion of each space was daylit and what proportion was non-daylit. Lighting could only be controlled in the daylit areas through photocontrols. Assuming that the installed lighting is uniform thought out the space, the daylit floor area to non-daylit floor area ratio could then be used to calculate the apportioned lighting power to be photocontrolled.

The project team reviewed two possible options to determine daylit areas.

- **Using Title-24 Method.** The 2005 version of Title 24 defines primary and secondary daylit areas as floor area one window head height (primary) and two window head heights (secondary) into the space and 2 feet on each side of a window. Further it instructs that overlapping daylit areas must not be double counted, and a permanent partition 60" in height truncates the daylit area. Luminaries that fall within or partially within the daylit areas are photocontrolled.
    - While this process of determining daylit areas was fairly easy to implement, the project team concluded that the simplifying assumptions about truncation of daylit areas by partitions and limiting daylit area to 2 feet on each side of the window were made primarily with code compliance in mind. In reality, daylit areas (especially secondary areas) may be smaller or larger, depending upon the daylighting design in the space.
- **Using Daylight Autonomy Plots.** The simulation results of hourly illuminance values from the 2ft x 2ft sensor grid could be processed into daylight autonomy plots that identified the area on a floor plan that achieved daylight autonomy at various percent levels. Primary and secondary daylit area could be thus defined using a threshold daylit

area percent value for each, such as 50 percent for primary area and 30 percent for secondary area.

  - The project team investigated this approach, and concluded that while this method would provide a more accurate representation of daylit area based on a particular design; it would mostly overestimate daylighting savings, due to the high level of precision that a 2ft x 2ft sensor grid produced, compared to a typical electric lighting grid at an 8ft x 10ft grid. Also electric lighting is typically zoned and controlled in rows running parallel to a façade which may not be a pattern followed by the daylight autonomy plots.

Based on the review of these two methods, the project team developed a hybrid approach which provided the required accuracy from the 2ft x 2ft sensor grid and had a more direct correlation to a lighting layout at an 8ft x 10ft grid.

4.2.1.1. Daylit Areas for Spaces in CEUS Dataset

The challenge in calculating daylit areas for the spaces in CEUS eQuest models was that, as discussed in Section 2.2, the window layouts in these models had been simplified into single large areas. Daylit areas for the spaces in the CEUS dataset were thus first calculated as the "maximum" possible daylit area (called DZmax) for each façade with windows. These DZmax areas were then scaled down based on the façade templates that each façade mapped to, resulting in the actual daylit area called DZactual.

Daylit areas for each of the 3,578 daylit spaces in the CEUS dataset were calculated using the following steps:

- For each exterior façade with windows in a space, first a maximum daylit area was designated. This area was 8 ft deep into the space and extended along the entire width of the façade. This was called a DZmax. A primary DZmax, secondary DZmax and a tertiary DZmax were created for each exterior façade, each 8 ft deep. These represent area served by the first, second and third rows of luminaires in a typical 8ft x 10ft luminaire grid. The 8ft dimension was also a close approximation of the window head height in most of the spaces. DZmax represents the maximum daylit area possible for a primary, secondary and tertiary zone. For skylit spaces, a skylit DZmax was calculated as area 0.7 times the ceiling height in each direction from the skylight edge.

- Then for each space, overlaps between the various DZmax areas were analyzed. Between two dissimilar overlapping zones, priority was given based on the following order:

    1. Skylit
    2. Primary
    3. Secondary
    4. Tertiary

  Thus, for example if a primary DZmax area overlaps with a secondary DZmax area, the overlapping area was assigned to the primary DZmax area, as it had higher priority, and so on.

  Between two similar overlapping zones, say if a secondary DZmax area overlaps with another secondary DZmax area, the overlapping areas were split equally (50/50).

- Once these DZmax areas were calculated for each space in the CEUS model, the areas were scaled down using a multiplier from the appropriate façade template, developed as described in the next section (4.2.1.2 Façade Template Multipliers). This scaled down daylit area was termed DZactual. DZactuals were calculated for each façade with windows for each space in the CEUS dataset, for primary, secondary, and tertiary areas as well as skylit areas.

Thus daylit areas, or DZactuals for primary, secondary and tertiary zones for each façade were calculated using the following formulae:

$$\boldsymbol{Primary\ DZactual = Primary\ DZmax\ \times Primary\ Facade\ Template\ Multiplier} \quad \textbf{Equation 1}$$

$$\boldsymbol{Secondary\ DZactual = SecondaryDZmax\ \times Secondary\ Facade\ Template\ Multiplier} \quad \textbf{Equation 2}$$

$$\boldsymbol{Tertiary\ DZactual = TertiaryDZmax\ \times Tertiary\ Facade\ Template\ Multiplier} \quad \textbf{Equation 3}$$

$$\boldsymbol{Skylit\ DZactual = SkylitDZmax\ \times Skylit\ Template\ Multiplier} \quad \textbf{Equation 4}$$

4.2.1.2 Façade Template Multipliers

As described in Section 0, template-spaces were either large, 60ft wide x 40ft deep or small, 20ft wide x 40ft deep, spaces with various façade designs on the outer 60ft or the 20ft wall, and typical office furniture layout on the interior. The 2ft x 2ft sensor grids in each template-space provided hour-by-hour values of illuminance for a full year from the annual Radiance simulations.

Façade Template Multipliers were calculated for each of the façade template models run in Radiance, using the following steps:

- Illuminance values from each sensor were first processed into daylight autonomy values, which represent the percent of occupied hours when the sensor received illuminance greater than 300 lux (or 30fc). Details and discussion on daylight autonomy as a metric for daylight sufficiency and assumptions used in its calculation can be found in the accompanying Daylighting Plus project report on Daylight Metrics (Heschong, 2011)
- To make the results from the 2ft x 2ft grid better correlated to a typical lighting layout, results from the 2ft x 2ft grid were converted into a larger 8ft x 10ft grid. An 8ft x 10ft grid represents the most typical office lighting layout of recessed troffers with 4ft, 2-lamp T8 luminaires. Each 8x10 grid 'block' represented area served by a single luminaire, and contained 20 sensors each.
- All 8x10 blocks that were in the first 8ft from the façade were termed 'primary zone blocks'. Similarly, those between 8ft and 16ft were termed 'secondary zone blocks', and those between 16ft and 24ft were termed 'tertiary zone blocks'.
- Each 8x10 block was then assigned a daylight autonomy value based on the daylight autonomy values of the 20 sensors that fall within. This value would represent percent hours that the luminaire that serves that 8x10 block can be switched off or dimmed. To ensure conservatism in our calculations, the 10th percentile value of daylight autonomy of the 20 sensors was chosen as the "critical task" value for the 8x10 block. This ensured that 'most' of the 20 sensors were reporting sufficient daylight autonomy for that sensor to be considered for switching or dimming.
- Next, the 8x10 block that contained the primary zone photosensor (described later in Section 0), was identified. This was always the 8x10 block in the middle of the facade, as the photosensor is located at the midpoint of the façade in each template-space. All primary zone blocks that were within 80 percent of the value of the primary zone photosensor block, were counted as an "include" block for the primary zone. Similarly, all "include" blocks for secondary, and tertiary zones were also identified.
- The total area of all "include" blocks for primary zone were summed up and divided by the total area of all blocks in the primary zone to calculate the Primary Façade Template Multiplier

Façade Template Multipliers for primary, secondary and tertiary zones were calculated using the following formulae:

$$\textbf{\textit{Primary Facade Template Multipler}} = \frac{\sum \textbf{\textit{Primary Zone Include Blocks Area}}}{\sum \textbf{\textit{All Primary Zone Blocks Area}}} \qquad \textbf{Equation 5}$$

$$\textbf{\textit{Secondary Facade Template Multipler}} = \frac{\sum \textbf{\textit{Secondary Zone Include Blocks Area}}}{\sum \textbf{\textit{All Secondary Zone Blocks Area}}} \qquad \textbf{Equation 6}$$

$$\boldsymbol{Tertiary\ Facade\ Template\ Multipler} = \frac{\sum \boldsymbol{Tertiary\ Zone\ Include\ Blocks\ Area}}{\sum \boldsymbol{All\ Tertiary\ Zone\ Blocks\ Area}} \qquad \textbf{Equation 7}$$

Templates spaces with skylights were considered fully daylit, as the skylights in the template space were designed to be no further than 1.4 times the ceiling height from each other. The assumption here was that a diffusing skylight can provide daylight 0.7 times ceiling height in each direction from its edge, a well-researched value that has been the basis for skylight design and Title 24. Thus for a skylit space:

$$\boldsymbol{Skylit\ Template\ Multipler} = \mathbf{1} \qquad \textbf{Equation 8}$$

4.2.2 Photosensor Location

A photosensor location was identified for the primary, secondary, tertiary and skylit zones in each template space. The sensor location represents a point on the workplane used to calibrate a photosensor. The photocontrols then dim or switch electric lights serving that zone to continuously maintain a threshold illuminance level. For this study, the threshold illuminance level was chosen as 300 lux (30 foot-candles), which is the IES recommended minimum illuminance for office spaces.

The sensor point is typically a point in a daylit zone that represents close to the lowest daylight levels for that zone, so that when electric lights are controlled to maintain a threshold illuminance level for that point, the rest of the zone has a combined daylight and electric lighting illuminance of more than the threshold value. Annual simulation programs such as DOE2 (eQuest), and Energy Plus have a default location for this sensor, which is 2/3rd the distance from the façade into the daylit zone from the mid-point of the facade.

For this study three photocontrol sensor points were identified for the sidelit template-spaces and one for the skylit template-spaces: all were located one foot from the rear of the daylit zone, and along the midline of the room. Thus for a space with three zones, the sensors were located at 7′, 15′ and 23′ from the window. Top-lit templates had only one photo control sensor. The top-lit photo control sensor was located mid-way between four skylights.

The illuminance values recorded by each photocontrol sensor (8,760 hours of daylight illuminance in lux) was then used to determine the operation of a dimming or switching system, that dims or switches electric lighting in each respective zone.

4.2.3 Annual Lighting Energy (ALE) Savings Calculation

Two types of lighting energy impacts from photocontrols were calculated: annual usage (kWh) and peak demand (kW).

Peak demand was calculated based on the method described in the 2008 DEER Update Report (DEER, 2008). The hottest 3-day heat wave that does not include weekends and holidays was designated as the peak demand period. The DEER demand period is from 2p.m. to 5p.m. on the days listed for each climate zone. Demand values are calculated as the average hourly energy reduction during these three three-hour periods.

Table 17: Peak Demand Period Used for DEER 2008)

Climate Zone	Start Date of 3-day period Month	Day	Weekday	Peak T (°F)	Average T (°F)	12p - 6p Ave T (°F)
CZ01	Sep	30	Mon	80	58	65
CZ02	Jul	22	Mon	99	78	93
CZ03	Jul	17	Wed	89	65	79
CZ04	Jul	17	Wed	97	71	87
CZ05	Sep	3	Tue	93	68	80
CZ06	Jul	9	Tue	85	69	77
CZ07	Sep	9	Mon	92	70	78
CZ08	Sep	23	Mon	98	78	89
CZ09	Aug	6	Tue	101	78	92
CZ10	Jul	8	Mon	104	83	99
CZ11	Jul	31	Wed	104	81	98
CZ12	Aug	5	Mon	103	81	100
CZ13	Aug	14	Wed	106	87	102
CZ14	Jul	9	Tue	106	90	103
CZ15	Jul	30	Tue	114	96	108
CZ16	Aug	6	Tue	96	73	89

Note: Blue is changes from 2005.)

Lighting energy savings were calculated by subtracting the annual lighting energy usage and peak demand of each CEUS office space without photocontrols (called 'original' lighting energy use and peak demand), to the annual lighting energy usage and peak demand of the same CEUS spaces with photocontrols (called 'modified' lighting energy use and peak demand). Then finally expansion weights from CEUS were applied to extrapolate the results to a statewide estimate.

Original lighting energy use and demand results were calculated from each space's annual lighting schedule (8,760 hrs.) directly from the CEUS dataset. Modified lighting energy use and demand results were calculated by applying the hourly daylight illuminance values (8,760 values) from the photocontrol sensors to determine the operation of a dimming or switching photocontrol system. The two photocontrol systems are described below.

4.2.3.1 Switching System

The switching system chosen for this study was a bi-level system that had three stages: On-50 percent-Off. This is the simplest switching system, which is most compatible with the bi-level wiring requirement for daylit zones that has been in place in Title 24 since early 1990s. Those existing spaces that complied with this requirement should have minimal or no rewiring requirements for adding photocontrols, a cost saving that will increase the cost effectiveness of the photocontrols retrofit.

The system operation can be described as follows: All lighting was turned off in a daylit zone if the photosensor received more than 30 fc of daylight illuminance. Half the lighting was turned off if the photosensor received more than 15 fc and less than 30 fc. The lighting was left fully on if less than 15 fc was incident on the photosensor.

4.2.3.2 Dimming System

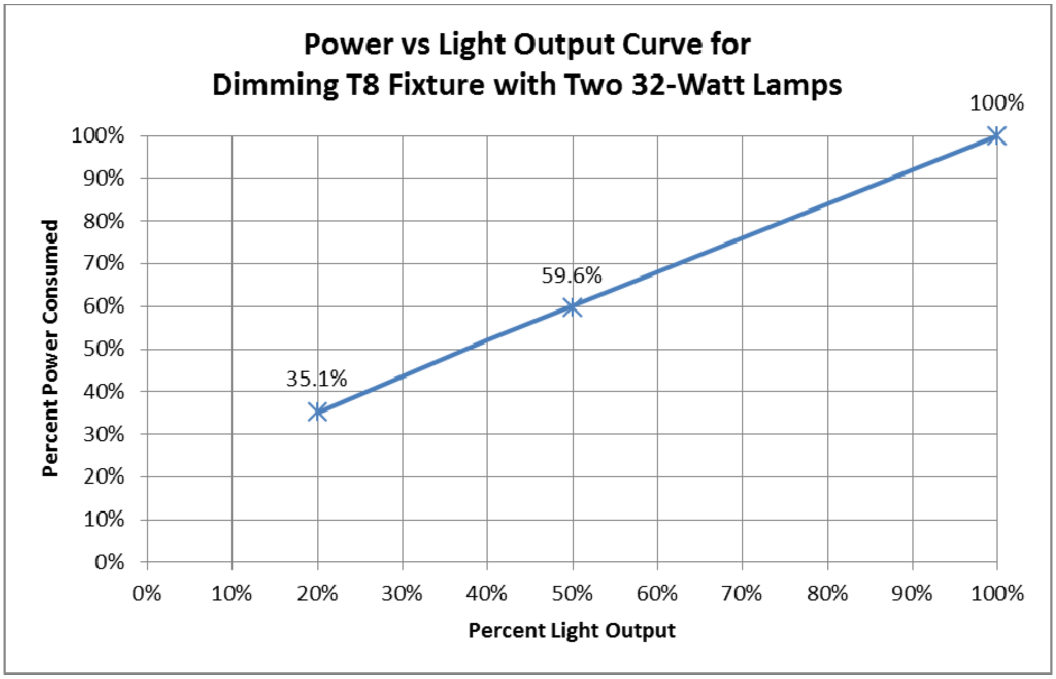
The dimming system chosen for this study was continuous fluorescent dimming up to 20 percent (20 percent Dimming). This system dims luminaires to a minimum level of 20 percent of light output (35.1 percent of full power), when sufficient daylight is available. At this stage, the lighting remains at 20 percent light output level, unless the lighting schedule for a space turns off the lighting, at which point the lighting and power consumption are both 0 percent. The system can thus be manually switched off based on the lighting schedule, but the automatic dimming does not switch the luminaire off completely.

Unlike the switching system, found in most existing offices, this would require a change-out of the ballasts to dimming ballasts. The advantage of the dimming system over the switching however is that dimming systems that do not turn off completely, are less perceptible during operation, which is expected to have a higher level of user acceptance, and they provide other advantages, such as demand response and occupant preference tuning potential.

An important difference between dimming and switching systems is that dimmed fluorescent lights use more power per lumen than fluorescent lights at full power. Figure 15 below shows the relationship between percent of light output versus watts consumed for a typical dimming ballast driving a 2-lamp T8 fixture. From the graph it can be seen that at 20 percent light output, power consumption is 35.14 percent of full power. At 50 percent light output, the power consumption is 59.6 percent of full power.

The data for the power versus light output curve in the figure below is reproduced from data about ballast power consumptions provided by Phillips, a major manufacturer of dimming ballasts (Becker, 2010 - email communication). Note that the watts consumed include power consumption by the ballast.

Figure 15: Power versus Light Curve Used for a Two 32W T8 Lamp Fixture



For the dimming system, the project team used the curve in figure 15 to translate light output required to meet design illuminance threshold to energy usage.

The system operation can be described as follows: All lighting was turned off if the lighting schedule indicates no lighting for that hour. When the photosensor received more than 30 fc of daylight illuminance, the lighting was dimmed all the way to 20 percent light output (35.1 percent power output). Between 30 and 0 fc, the lighting was dimmed in 60 steps. At each step, the lighting power was calculated from the percentage-of-full lighting output required based on the data in figure 15.

Dimming systems that have the ability to dim the lighting to a set point (say 20 percent light output) and then switch the lighting off automatically in response to daylight (20 percent Dimming + Off) are also available. These systems tend to have a small cost premium compared to one that dims up to system modeled in this study (20 percent Dimming).

4.3 Lighting and HVAC Energy Savings

When electric lights are turned off or dimmed, the associated heat from those lights is also reduced. This is seen as a reduced cooling load in the summer time, and an increased heating load for the HAVC system. Given California climate conditions, the magnitude of cooling energy savings is typically higher than the magnitude of heating energy increase.

To estimate the effect of turning off electric lights using photocontrols on HVAC energy use in the CEUS space, the project team utilized the Database for Energy Efficient Resources (DEER) interactive HVAC factors (DEER, 2008). These factors provide a means to scale the energy savings calculated from lighting-only to lighting and HVAC savings. The savings are calculated based on the DEER prototype buildings, of which the Small Office and Large Office were used for this study. Further details on the HVAC assumptions and the prototype buildings can be found in 2008 DEER report (DEER, 2008).

Table 18 and Table 19 below provide the HVAC interaction factors for Large and Small Office building type, by utility territory and climate zones.

Table 18: DEER HVAC Interaction Factors for Large Office

			HVAC Factors		
Building Type	Climate Zone		Energy kWh/kWh	Demand kW/kW	Gas therm/kWh
LOFF	1	PG&E (CA)	1.0976	1.2365	-0.0083
LOFF	2	PG&E (CA)	1.1000	1.3524	-0.0071
LOFF	3	PG&E (CA)	1.1088	1.3253	-0.0063
LOFF	4	PG&E (CA)	1.1262	1.3531	-0.0055
LOFF	5	PG&E (CA)	1.1215	1.3022	-0.0056
LOFF	11	PG&E (CA)	1.1109	1.3906	-0.0077
LOFF	12	PG&E (CA)	1.1098	1.3762	-0.0070
LOFF	13	PG&E (CA)	1.1432	1.3655	-0.0057
LOFF	16	PG&E (CA)	1.0148	1.3384	-0.0140
LOFF	IOU	PG&E (CA)	1.1142	1.3429	-0.0063
LOFF	5	SCE (CA)	1.1357	1.3113	-0.0062
LOFF	6	SCE (CA)	1.1596	1.3069	-0.0041
LOFF	8	SCE (CA)	1.1704	1.3587	-0.0042
LOFF	9	SCE (CA)	1.1727	1.3703	-0.0047
LOFF	10	SCE (CA)	1.1566	1.2774	-0.0042
LOFF	13	SCE (CA)	1.1582	1.3616	-0.0057
LOFF	14	SCE (CA)	1.1327	1.3076	-0.0065
LOFF	15	SCE (CA)	1.2277	1.3508	-0.0028
LOFF	16	SCE (CA)	1.0411	1.3075	-0.0127
LOFF	IOU	SCE (CA)	1.1659	1.3379	-0.0044
LOFF	6	SDG&E (CA)	1.1536	1.2621	-0.0021
LOFF	7	SDG&E (CA)	1.1601	1.2758	-0.0021
LOFF	8	SDG&E (CA)	1.1641	1.3288	-0.0022
LOFF	10	SDG&E (CA)	1.1522	1.2354	-0.0026
LOFF	14	SDG&E (CA)	1.1350	1.2553	-0.0038
LOFF	15	SDG&E (CA)	1.2252	1.3219	-0.0017
LOFF	IOU	SDG&E (CA)	1.1587	1.2695	-0.0022

Table 19: DEER HVAC Interaction Factors for Small Office

Building Type	Climate Zone		HVAC Factors Energy kWh/kWh	HVAC Factors Demand kW/kW	HVAC Factors Gas therm/kWh
SOFF	1	PG&E (CA)	1.0385	1.1750	-0.0047
SOFF	2	PG&E (CA)	1.0571	1.2149	-0.0039
SOFF	3	PG&E (CA)	1.0637	1.2318	-0.0030
SOFF	4	PG&E (CA)	1.0769	1.2266	-0.0028
SOFF	5	PG&E (CA)	1.0803	1.2116	-0.0020
SOFF	11	PG&E (CA)	1.0593	1.2385	-0.0048
SOFF	12	PG&E (CA)	1.0671	1.2281	-0.0042
SOFF	13	PG&E (CA)	1.0912	1.2447	-0.0032
SOFF	16	PG&E (CA)	0.9851	1.2259	-0.0085
SOFF	IOU	PG&E (CA)	1.0712	1.2311	-0.0035
SOFF	5	SCE (CA)	1.1225	1.2677	-0.0022
SOFF	6	SCE (CA)	1.1477	1.2835	-0.0012
SOFF	8	SCE (CA)	1.1577	1.2944	-0.0013
SOFF	9	SCE (CA)	1.1596	1.3154	-0.0013
SOFF	10	SCE (CA)	1.1406	1.2791	-0.0012
SOFF	13	SCE (CA)	1.1277	1.3131	-0.0031
SOFF	14	SCE (CA)	1.1092	1.2918	-0.0030
SOFF	15	SCE (CA)	1.1987	1.3064	-0.0006
SOFF	16	SCE (CA)	0.9966	1.2833	-0.0078
SOFF	IOU	SCE (CA)	1.1489	1.2930	-0.0015
SOFF	6	SDG&E (CA)	1.1540	1.2789	-0.0005
SOFF	7	SDG&E (CA)	1.1582	1.2529	-0.0004
SOFF	8	SDG&E (CA)	1.1621	1.2796	-0.0005
SOFF	10	SDG&E (CA)	1.1623	1.2750	-0.0007
SOFF	14	SDG&E (CA)	1.1231	1.2834	-0.0025
SOFF	15	SDG&E (CA)	1.2130	1.2991	-0.0003
SOFF	IOU	SDG&E (CA)	1.1588	1.2580	-0.0004

CHAPTER 5: Analysis and Findings

This section provides the results for the statewide impact of photocontrols, and the impact of daylighting improvements. Since the CEUS database was the basis for this study, the statewide estimate is representative of the population captured by the CEUS survey. As described in the CEUS report (CEUS, 2006), the term "statewide" refers to the service areas of the four electric utilities represented in the CEUS database: PG&E, SCE, SDG&E, and SMUD. Other areas of the state were omitted from the analysis because they were not covered by the survey. The results are strictly limited to only the covered electric service areas.

The three IOUs (PG&E, SCE, SDG&E) represent 72 percent of commercial electricity usage in the state. SMUD represents about another 5 percent. Thus the "statewide' results presented in this report represent only about 77 percent of the full statewide use. Multiplying the statewide values in this report by a factor of 1.28 provides a better estimate of the energy potential for the entire state of California.

The 2006 CEUS database was completed in 2005 and provides a snap-shot of energy use in existing commercial buildings in California for the year 2002 (except SMUD territory that uses a 2003 commercial frame). While this report is dated 2011, the statewide results presented here are only representative of office buildings built up until 2002.

5.1 Statewide Results for Energy and Demand Savings From Photocontrols

This section provides an estimate of statewide energy savings from adding photocontrols to existing office spaces in California. The results are provided at a statewide level as well as by utility territory, and further by utility territory and climate zones. This section provides mostly statewide or statewide and utility territory results, the remaining results tables are provided in Appendix E.

5.1.1 Results Statewide and by Utility Territory

Table 20 through Table 23 provide annual energy and demand savings estimates from daylighting (for example, adding 2-level switching photocontrols to existing office space). Results are presented at a statewide level and also at the level of each major California utility, that form a part of the CEUS dataset. The savings were calculated for a 2-level switching photocontrol system. The results are also separated by SOFF or Small Office (<30k sq ft) and LOFF or Large office (>30k sq ft), and All office buildings, as defined in CEUS.

Table 20 provides lighting-only energy and demand savings for a statewide estimate, while Table 21 provides lighting and HVAC savings for a statewide estimate. Table 21 shows negative natural gas (therm) savings, since turning electric lighting off will result in a slight increase in HVAC heating load in winter.

Table 22 provides lighting-only energy and demand savings delineated by utility territories while Table 23 provides combined lighting and HVAC savings for the same utility territories. Table 21 and Table 23 also shows negative natural gas (therms) savings.

Detailed energy savings by utility territory and climate zone are provided in Appendix E.

The following are explanations of the column headings in Table 20 through Table 23.

Energy Savings (GWh):	Total energy savings for all office buildings in the defined category in Gigawatt-hours.
Demand Savings (MW):	Total demand savings for all office buildings in the defined category in Megawatt-hours. Demand period defined in Section4.2.
Gas Savings (Mtherms):	Total gas savings for all office buildings in the defined category in million Therms.

Table 20: Statewide Energy and Demand Savings − Lighting Only

LIGHTING SAVINGS Only

Results for >> **CA Statewide**

	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	406.07	141.55
SOFF	184.35	68.33
LOFF	221.72	73.22

Table 21: Statewide Energy and Demand Savings - Lighting and HVAC

LIGHTING AND HVAC SAVINGS

Results for >> **CA Statewide**

	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherm
All Office Bldgs	458.53	184.24	(1.56)
SOFF	207.00	86.32	(0.37)
LOFF	251.53	97.92	(1.19)

Table 22: Energy and Demand Savings by IOU Territory − Lighting Only

LIGHTING SAVINGS Only								
	All CZs		All CZs		All CZs		All CZs	
Results for >>	PG&E		SMUD		SCE		SDG&E	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	176.43	61.93	20.59	7.02	153.84	52.65	55.22	19.95
SOFF	59.85	22.61	6.11	2.23	82.76	29.75	35.64	13.74
LOFF	116.58	39.32	14.48	4.79	71.08	22.90	19.58	6.21

Table 23: Energy and Demand Savings by IOU Territory − Lighting and HVAC

LIGHTING AND HVAC SAVINGS												
	All CZs			All CZs			All CZs			All CZs		
Results for >>	PG&E			SMUD			SCE			SDG&E		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	194.01	80.64	(0.94)	22.59	9.33	(0.13)	177.95	69.10	(0.43)	63.98	25.17	(0.06)
SOFF	64.11	27.84	(0.21)	6.52	2.73	(0.03)	95.07	38.47	(0.12)	41.29	17.28	(0.02)
LOFF	129.90	52.81	(0.73)	16.06	6.59	(0.10)	82.88	30.63	(0.31)	22.69	7.89	(0.04)

The results show that the total annual statewide energy and demand savings from 'all office buildings', using a 2-level switching photocontrols system was 458.53 GWh and 184.24 MW, when lighting and associated HVAC savings are considered together. The tables also show that the energy and demand savings were fairly evenly split between small and large offices at the statewide level. However, when broken down by utility, the split between energy savings from small and large offices was not even, and varied by utility territory.

The tables also show that the increase in heating energy was small in magnitude compared to the electric energy and demand savings.

5.1.2 Results by Building Area

Results in this section are provided as energy and demand savings per square foot of office floor area. In Table 24 and Table 25 savings are per square foot of office building area (Building level analysis), while in Table 26 and Table 27 savings are per square foot of office space area (Space level analysis) .

In the building level analysis, building area consists of all spaces in the building, including the daylit perimeter as well as the non-daylit core. The savings were calculated for a 2-level switching photocontrol system. The results were also separated by Small Office versus Large Office, and then into three groups, namely spaces with Gross window-to-wall-ratio (Gross

WWR) > 0.20, < 0.20, and the presence of skylights. Gross WWR of 0.20 was chosen as it was the median Gross WWR for spaces with windows (from table 3 in Section 3.1.1 on Window Properties). Spaces that fell in the skylight category may have windows, but those in Gross WWR < 0.20 or Gross WWR > 0.20 categories did not have skylights.

Note about Net versus Gross Window-to-Wall-Ratios. Window-to-wall-ratio in the building level analysis is the 'Gross WWR' calculated at the building level. This is calculated using the total exterior wall area for a building, as seen from the outside. The wall area hence includes plenum walls. The total wall area is divided by the total window area in the building to calculate the **Gross WWR**.

In the space level analysis, the window-to-wall-ratio is the '**Net WWR**'. This is calculated using total exterior wall area for every space, as seen from the inside, from floor to ceiling, and does not include plenum walls. Total window area is then divided by this floor to ceiling wall area to calculate the Net WWR.

Table 24 and Table 25 show savings at a California statewide level. Detailed energy savings by utility territory and climate zone are provided in Appendix D.

The following are explanations of the column headings in Table 24 and Table 25.

Energy Savings per Bldg sf (kWh/sf-yr):	Average annual energy savings for all office buildings in the defined category per square foot of building area.
Peak Demand Reduction per Bldg sf (W/sf):	Average peak demand reduction for all office buildings in the defined category per square foot of building area.
Total Building Area (Msf):	Total building area for all office buildings in the defined category in million sf.
Average Building Area (sf):	Average building area for all office buildings in the defined category in sf.
% Bldg area in primary daylit zone (%):	Average percent of building area that falls under primary daylit zone, in the defined category. For skylight category, the primary daylit zone is the same as the skylit zone. Primary and skylit zones as defined in Section 4.2
% Bldg area in all daylit zones (%):	Average percent of building area that falls in either primary, secondary, tertiary or skylit daylit zones, in the defined category. Daylit zones as defined in Section 4.2.

% Energy savings - primary daylit zones (%): Average percent of total energy savings that were in the primary daylit zone. For skylit category, the primary daylit zone is the same as the skylit zone.

Table 24: Energy and Demand Savings per Square Foot at Building Level – Lighting Only

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

Results for >> **CA Statewide**

		Energy Savings per Bldg sf kWh/sf-yr	Peak Demand Reduction per Bldg sf W/sf	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.62	0.23	1002.75	7,088	23%	31%	76%
SOFF	Gross WWR < .20	0.60	0.22	237.51	2,204	23%	30%	77%
	Gross WWR > .20	0.85	0.31	76.95	4,915	22%	37%	67%
	Skylight	0.75	0.31	37.03	4,352	35%	40%	93%
LOFF	Gross WWR < .20	0.24	0.08	180.05	60,674	8%	10%	72%
	Gross WWR > .20	0.42	0.14	407.71	75,081	12%	16%	73%
	Skylight	0.41	0.14	63.50	55,592	14%	17%	93%

Table 25: Energy and Demand Savings per Square Foot at Building Level – Lighting and HVAC

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

Results for >> **CA Statewide**

		Energy Savings per Bldg sf kWh/sf-yr	Peak Demand Reduction per Bldg sf W/sf	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.70	0.29	1002.75	7,088	23%	31%	76%
SOFF	Gross WWR < .20	0.66	0.27	237.51	2,204	23%	30%	77%
	Gross WWR > .20	0.95	0.39	76.95	4,915	22%	37%	67%
	Skylight	0.86	0.41	37.03	4,352	35%	40%	93%
LOFF	Gross WWR < .20	0.28	0.11	180.05	60,674	8%	10%	72%
	Gross WWR > .20	0.47	0.19	407.71	75,081	12%	16%	73%
	Skylight	0.45	0.18	63.50	55,592	14%	17%	93%

Average lighting and HVAC energy savings calculated per square foot of office building area for all office buildings in California was 0.70 kWh/sf-yr and peak demand reduction was 0.29 W/sf. The average office building in California was 7,088 sf. The average percent building area in primary daylight zones was 23 percent, while the average percent building area in all daylit zones (Primary, secondary and tertiary) was 31 percent. As can be expected, on average, about three quarters of the total energy saving (76 percent) was in the primary daylit zones.

The results broken down by small and large office show that annual energy savings per building square foot in small office buildings was consistently higher than that of large offices. This is an expected result as daylighting savings are mainly found in the perimeter of a floor plan (for sidelit office spaces), and large offices have larger floor plans, compared to small offices thus the savings intensity is lower for large offices. Small offices with Gross WWR > 0.20 had the highest average savings per square foot at 0.95 kWh/sf. The average savings were 44 percent to 67 percent higher for buildings with Gross WWR > 0.20, compared to those with Gross WWR < 0.20. Buildings with skylights were found to have annual energy savings between those with Gross WWR > 0.20 and < 0.20.

The tables also provide the total building area under each category in million sf (Msf). The results show that most small offices (68 percent) have Gross WWR < 0.20, whereas most large offices (63 percent) have Gross WWR > 0.20. As per total building area, small offices make up about 35 percent of all office buildings, while large offices make up the a larger portion at 65 percent of all office area.

In general it was found that small offices buildings tend to have high energy and peak demand savings intensity, but there is almost two times as much large office building area, as there is a small office building area in California. The average large office size is about 10 to 14 times the average small office.

5.1.3 Results by Space Area

Table 26 and Table 27 provide statewide energy and demand savings estimates per square foot of HVAC zone area called 'space area' in this report (Space level analysis) and per square foot of daylit zone area (Zone level analysis). The spaces were defined by the HVAC zones inherited from the CEUS models, as explained in section 1.1, while the daylit zones were defined in the subsequent analysis of Dynamic Radiance output, as explained in section 4.2.1.

In the space level analysis, the space area consists of all spaces in a building that have at least one daylit zone, for example, spaces with at least one window or a skylight. Theses spaces represent areas that have "daylighting potential", and thus exclude spaces such as core elevator lobbies or interior corridors with no window or skylights. These spaces are referred to in this section as "daylit spaces" and their areas as "daylit space area"

In the zone level analysis, a "daylit zone" is defined as the primary daylit zone in sidelit spaces and skylit daylit zone in toplit spaces. The corresponding area is referred to in this section as "daylit zone area"

All savings were calculated for a 2-level switching photocontrol system. The results were also separated into three groups, namely spaces with Net window-to-wall-ratio (Net WWR) > 0.40, < 0.40, and the presence of skylights. Net WWR of 0.40 was chosen as it was the median Net WWR for spaces with windows (from Table 3 in Section 3.1.1 on Window Properties). Spaces that fell in the skylight category may have windows, but those in Net WWR < 0.40 or Net WWR > 0.40 categories did not have skylights.

Detailed energy savings by utility territory and climate zone are provided in the Appendix D.

The following are explanations of the column headings in Table 25 and Table 26.

Energy Savings per Space sf (kWh/sf-yr): Average annual energy savings for all office spaces with daylighting potential in the defined category per square foot of space area.

Peak Demand Reduction per Space sf (W/sf): Average peak demand reduction for all office spaces with daylighting potential in the defined category per square foot of space area.

Energy Savings per Primary Daylit Zone sf (kWh/sf-yr): Average annual energy savings for all primary daylit zones in the defined category per square foot of space area. For skylight category, the primary daylit zone is the same as the skylit zone.

Peak Demand Reduction per Primary Daylit Zone sf (W/sf): Average peak demand reduction for all primary daylit zones in the

	defined category per square foot of space area. For skylight category, the primary daylit zone is the same as the skylit zone.
Total Space Area (Msf):	Total area for all office spaces with daylighting potential in the defined category in million sf.
Average Space Area (sf):	Average area for all office spaces with daylighting potential in the defined category in sf.
% Space area in primary daylit zone (%):	Average percent of space area that falls under primary daylit zone, in the defined category. For skylight category, the primary daylit zone is the same as the skylit zone. Primary and skylit zones as defined in Section 4.2.
% Space area in all daylit zones (%):	Average percent of space area that falls in either primary, secondary, tertiary or skylit daylit zones, in the defined category. Daylit zones as defined in Section 4.2.
% Energy savings - primary daylit zones (%):	Average percent of total energy savings that were in the primary daylit zone. For skylit category, the primary daylit zone is the same as the skylit zone.

Table 26: Energy and Demand per Square Foot – at Space and Zone Level – Lighting Only

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

	Energy Savings per Space sf kWh/sf-yr	Peak Demand Reduction per Space sf W/sf	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.76	0.28	2.11	0.75	728.44	2,263	27%	35%	74%
Spaces with Net WWR < .40	0.66	0.25	2.01	0.74	473.91	2,045	26%	32%	74%
Spaces with Net WWR > .40	1.04	0.35	2.38	0.76	202.05	2,579	30%	42%	69%
Spaces with skylights	0.79	0.32	2.21	0.91	52.49	4,451	36%	40%	95%

Table 27: Energy & Demand Savings per Square Foot - at Space and Zone Level - Lighting and HVAC

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

	Energy Savings per Space sf kWh/sf-yr	Peak Demand Reduction per Space sf W/sf	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.91	0.38	2.26	0.85	728.44	2,263	27%	35%	74%
Spaces with Net WWR < .40	0.79	0.34	2.14	0.83	473.91	2,045	26%	32%	74%
Spaces with Net WWR > .40	1.24	0.48	2.57	0.89	202.05	2,579	30%	42%	69%
Spaces with skylights	0.90	0.42	2.32	1.01	52.49	4,451	36%	40%	95%

Average lighting and HVAC energy savings calculated per square foot of daylit space area for all office buildings in California was 0.91 kWh/sf-yr and peak demand reduction was 0.38 W/sf. The same energy savings per square foot of daylit zone area was 2.26 kWh/sf-yr and peak demand reduction was 0.85 W/sf. The values for savings per square foot of daylit zone area are higher because the same energy savings are being divided by a smaller area as compared to savings per square foot of space area.

The average space size was 2,263 sf. The average percent daylit space area in primary daylight zones was 27 percent, while the average percent building area in all daylit zones (Primary, secondary and tertiary) was 35 percent. As seen in the building level analysis, on average, about three quarters of the total energy saving (74 percent) was in the primary daylit zones.

The results broken down by Net WWR <0.40 and >0.40 show that average annual energy savings was the highest for Net WWR > 0.40, at 1.24 kWh/sf-yr of daylit spaces and 2.57 kWh/sf-yr of daylit zones. However, spaces with WWR > 0.40 makeup only about 28 percent of the total daylit space area. Spaces with Net WWR <0.40 make up a larger 65 percent of the total daylit space area. The average savings were 56 percent higher for buildings with Net WWR > 0.40, compared to those with Net WWR < 0.40. As seen in the building level analysis, spaces with skylights were found to have annual energy savings between those with Net WWR > 0.40 and < 0.40.

5.2 Results for Energy and Demand Savings From Daylighting Improvements

Table 28 and Table 29 provide energy and demand savings estimates at the space level from daylight improvements, for example, various improvements to the spaces to enhance daylight availability in addition to adding photocontrols. The savings were calculated for a 2-level switching photocontrol system and a dimming photocontrol system separately. The results were also separated into three groups, namely spaces with Net window-to-wall-ratio (Net WWR) > 0.40, < 0.40, and the presence of skylights. Net WWR of 0.40 was chosen as it was the median Net WWR for spaces with windows (from Table 3 in Section 3.1.1 on Window Properties). Spaces that fell in the skylight category may have windows, but those in Net WWR < 0.40 or Net WWR > 0.40 categories did not have skylights.

Initially six categories of improvements were identified; however two of the categories - advanced inverted blinds, and split blinds - were dropped from the final analysis, because of the following reasons. As explained in Section4.1.4, the project team was limited to using BSDFs from the Window 6 software, which currently does not have the built-in capability to model inverted blinds. A split blind was modeled with a static angled Venetian blind on the clerestory, and an operable venetian blind on the view window, however the correct base case for comparison, blinds always closed, was not available.

PC Only: Base case savings, results for only adding photocontrols to existing spaces as-is. The results are for either 2-level switching photocontrols (Table 28), or dimming photocontrols (Table 29). Details of the dimming and switching systems used are provided in Section4.2.3.

The four improvement categories for which results are reported are as follows:

FF01: Reduce furniture partition height from 60” to 45”

FF02: Reduce furniture partition height from 60” to 30”

IS01: Increase interior surface reflectance from 20/50/70 to 30/60/85,where the values are for floor/wall/ceiling

LS01: Change from no light shelves on any windows to adding 3' deep light shelves located 8' above the floor. Light shelves were added to only South, South-East or South-West facing windows, in spaces with ceiling height was 10' ceiling or more, and the ceiling ht. - head ht. differential was 0 ft.

The following are explanations of the column headings in Table 28 and Table 29.

Energy Savings per Space sf (kWh/sf-yr): Average annual energy savings for all office spaces with daylighting potential in the defined category per square foot of space area.

Percent Savings Increase (%): Percentage of increase in energy savings compared to base case savings from PC only

Peak Demand Reduction per Space sf (W/sf): Average peak demand reduction for all office spaces with daylighting potential in the defined category per square foot of space area.

Percent Demand Reduction Increase (%): Percentage of increase in peak demand reduction compared to base case savings from PC only

Energy Savings per Primary Daylit Zone sf (kWh/sf-yr): Average annual energy savings for all primary daylit zones in the defined category per square foot of space area. For skylight category, the primary daylit zone is the same as the skylit zone.

Peak Demand Reduction per Primary Daylit Zone sf (W/sf): Average peak demand reduction for all primary daylit zones in the defined category per square foot of space area. For skylight category, the primary daylit zone is the same as the skylit zone.

Total Space Area (Msf): Total area for all office spaces with daylighting potential in the defined category in million sf.

Average Space Area (sf): Average area for all office spaces with daylighting potential in the defined category in sf.

% Space area in primary daylit zone (%): Average percent of space area that falls under primary daylit zone, in the defined category. For skylight category, the primary daylit zone is the same as the skylit zone. Primary and skylit zones as defined in Section4.2.

% Space area in all daylit zones (%): Average percent of space area that falls in either primary, secondary, tertiary or skylit daylit zones, in the defined category. Daylit zones as defined in Section4.2.

% Energy savings - primary daylit zones (%): Average percent of total energy savings that were in the primary daylit zone. For skylit category, the primary daylit zone is the same as the skylit zone.

Table 28: Energy and Demand Savings − Improvements with Switching Controls − Lighting and HVAC

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

			Energy Savings per Space sf kWh/sf-yr	Percent Savings Increase %	Peak Demand Reduction per Space sf W/sf	Percent Demand Reduction Increase %	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
2-level Switching	**All Daylit Spaces**	PC's Only	0.91	-	0.38	-	2.26	0.85	728.44	2,263	27%	35%	74%
		FF01	0.97	7%	0.40	6%	2.47	0.99	728.44	2,263	26%	39%	69%
		FF02	0.95	4%	0.39	3%	2.42	0.98	728.44	2,263	26%	41%	69%
		IS01	1.04	15%	0.44	17%	2.61	1.07	728.44	2,263	28%	39%	70%
		LS01	0.91	0%	0.38	0%	2.49	1.00	728.44	2,263	27%	35%	74%
	Net WWR < .40	PC's Only	0.79	-	0.34	-	2.14	0.83	473.91	2,045	26%	32%	74%
		FF01	0.79	0%	0.33	-1%	2.27	0.93	473.91	2,045	24%	35%	69%
		FF02	0.75	-5%	0.31	-8%	2.22	0.92	473.91	2,045	23%	38%	70%
		IS01	0.89	13%	0.39	16%	2.44	1.02	473.91	2,045	27%	36%	70%
		LS01	0.76	-4%	0.32	-5%	2.29	0.94	473.91	2,045	26%	32%	74%
	Net WWR > .40	PC's Only	1.24	-	0.48	-	2.57	0.89	202.05	2,579	30%	42%	69%
		FF01	1.36	10%	0.52	10%	2.71	0.98	202.05	2,579	32%	49%	64%
		FF02	1.41	14%	0.54	14%	2.67	0.98	202.05	2,579	33%	53%	63%
		IS01	1.32	6%	0.50	6%	2.78	1.00	202.05	2,579	31%	46%	66%
		LS01	1.19	-4%	0.46	-4%	2.73	0.99	202.05	2,579	30%	42%	69%
	Skylight	PC's Only	0.90	-	0.42	-	2.32	1.01	52.49	4,451	36%	40%	95%
		FF01	0.69	-23%	0.32	-25%	2.65	1.24	52.49	4,451	27%	34%	92%
		FF02	0.68	-25%	0.31	-27%	2.65	1.24	52.49	4,451	27%	35%	93%
		IS01	0.94	4%	0.43	3%	2.72	1.27	52.49	4,451	36%	42%	93%
		LS01	0.87	-4%	0.41	-4%	2.65	1.26	52.49	4,451	36%	40%	95%

Table 29: Energy & Demand Savings - improvements with Dimming Controls - Lighting and HVAC

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

			Energy Savings per Space sf kWh/sf-yr	Percent Savings Increase %	Peak Demand Reduction per Space sf W/sf	Percent Demand Reduction Increase %	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
Dimming	**All Daylit Spaces**	PC's Only	0.83	-	0.34	-	1.97	0.73	728.44	2,263	27%	35%	71%
		FF01	0.89	7%	0.36	7%	2.16	0.85	728.44	2,263	26%	39%	64%
		FF02	0.89	8%	0.36	6%	2.13	0.85	728.44	2,263	26%	41%	63%
		IS01	0.94	13%	0.39	13%	2.22	0.88	728.44	2,263	28%	39%	66%
		LS01	0.83	0%	0.34	0%	2.17	0.86	728.44	2,263	27%	35%	71%
	Net WWR < .40	PC's Only	0.75	-	0.32	-	1.92	0.73	473.91	2,045	26%	32%	71%
		FF01	0.76	1%	0.32	0%	2.03	0.83	473.91	2,045	24%	35%	64%
		FF02	0.75	-1%	0.31	-4%	2.01	0.82	473.91	2,045	23%	38%	62%
		IS01	0.83	10%	0.35	10%	2.11	0.86	473.91	2,045	27%	36%	66%
		LS01	0.72	-4%	0.31	-5%	2.05	0.83	473.91	2,045	26%	32%	71%
	Net WWR > .40	PC's Only	1.04	-	0.39	-	2.11	0.71	202.05	2,579	30%	42%	67%
		FF01	1.16	11%	0.43	11%	2.22	0.79	202.05	2,579	32%	49%	61%
		FF02	1.21	16%	0.46	17%	2.20	0.79	202.05	2,579	33%	53%	59%
		IS01	1.10	6%	0.41	5%	2.25	0.80	202.05	2,579	31%	46%	63%
		LS01	1.00	-4%	0.37	-4%	2.22	0.79	202.05	2,579	30%	42%	66%
	Skylight	PC's Only	0.80	-	0.35	-	2.00	0.80	52.49	4,451	36%	40%	93%
		FF01	0.63	-22%	0.27	-23%	2.29	0.99	52.49	4,451	27%	34%	89%
		FF02	0.63	-21%	0.27	-23%	2.29	0.99	52.49	4,451	27%	35%	89%
		IS01	0.82	3%	0.36	2%	2.33	1.01	52.49	4,451	36%	42%	91%
		LS01	0.77	-4%	0.33	-4%	2.29	1.00	52.49	4,451	36%	40%	93%

5.2.1 Results for Interior Surface Reflectance

Of the four improvements reported, increasing interior surface reflectances (IS01) was found to be the most consistent at providing energy and demand savings across all three space categories, Net WWR < 0.40, Net WWR > 0.40 and Skylit spaces. It also had the highest average energy savings improvement at 15 percent with 2-level switching systems and 13 percent with dimming systems, across all three space categories. Increasing interior reflectances showed greater increase in savings for sidelit spaces, and a lesser increase for toplit spaces. This is intuitive as, light from windows bounces more often before reaching a workplane, than light from skylights coming straight down.

5.2.2 Results for Furniture Partition Height

Reducing furniture partition heights from 60” to 45” (FF01) and 60” to 30” (FF02) also showed significant energy savings improvements, but only in those spaces with larger window areas, for example Net WWR > 0.40. For those spaces with larger window areas, the savings increase was 10 percent for FF01 and 14 percent for FF02 with a 2-level switching systems and 11 percent and 16 percent respectively with a dimming system. This result also showed that greatest boost in energy savings is achieved in reducing partition heights from 60” to 45”; reducing partition heights further by another 15” to 30” has significant, but much smaller improvement. In spaces with smaller window areas, for example Net WWR < 0.40, the savings were not significantly affected by this improvement. The slight negative values seen in some of the results are explained and discussed in section 5.2.1.

5.2.3 Results for Light Shelves

The results show that an average for all office spaces in the state, there was minimal or no improvement from light shelves. A possible reason for this is that as noted in Section 4.1.4, light shelves were only included if the space was South, South-East or South-West facing, had a ceiling height of 10' or more and windows extends to the top of the ceiling. This condition was only met in 11.2 percent of all statewide office area (15.4 percent of daylit spaces). The remaining 88.8 percent of space area did not qualify for light shelves. The value of 11.2 percent represents the statewide market potential for light shelves in California. The savings in only those spaces that received light shelves in our analysis is provided in Table 30.

Table 30: Energy and Demand Savings Only Spaces With Light Shelves - Lighting and HVAC

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

		Energy Savings per Space sf kWh/sf-yr	Percent Savings Increase %	Peak Demand Reduction per Space sf W/sf	Percent Demand Reduction Increase %	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
2-level Switching	PC's Only	1.06	-	0.41	-	3.29	1.19	112.05	4,666	24%	36%	78%
	LS01 (Spaces with LS)	1.08	3%	0.41	1%	3.30	1.20	112.05	4,666	24%	36%	76%
Dimming	PC's Only	0.92	-	0.34	-	2.73	0.97	112.05	4,666	24%	36%	74%
	LS01 (Spaces with LS)	0.93	1%	0.35	1%	2.73	0.97	112.05	4,666	24%	36%	73%

These results show when only those spaces are considered that are suitable for light shelves, the measure has a small bump in energy savings of 3 percent with a 2-level switching system and 1 percent with a dimming system. Peak demand reduction also has a slightly bump of about 1 percent. Light shelves redirect light and bounce it deeper into the space, thus the expected result was to see an increase in percent space area in primary as well as all daylit zones. However the results in Table 30 show the percent space area in primary daylit zone as well as all daylit zones remained the same. However there was a small decrease in percent energy savings in the primary daylit zone in the case with light shelves. This was an intuitive result as it indicated that adding light shelves reduced illuminance in the primary daylit zone, and increased it in the secondary and tertiary zones, which resulted in the slight increase in savings.

5.2.4 Results for Dimming Photocontrols

The results show in spaces with lower window to wall ratios where marginal daylighting conditions are expected, the dimming system saves more energy. In other cases the 2-level switching system provides more savings. The dimming system employed in this study was a 20 percent dimming system that dims the lighting to a minimum level of 20 percent light output, but does not switch the luminaire off. A dimming system that switches the lighting off when sufficient daylit is available, instead of leaving the lights dimming at a minimum level, can be expected to have similar or greater energy savings compared to 2-level switching systems.

Generally, a dimming system will save more energy than a switching system when lighting needs or climate conditions are highly variable, and therefore adjustments in illuminance output are made several times per day. Under highly stable daylighting conditions, such as all sunny, or all overcast, with no variable shadowing or reflections from clouds or neighboring structures, switching systems are often found to save more energy, since they only need to respond twice a day, once in the morning and once in the afternoon.

5.2.5 Discussion of Furniture Height Improvement Results in Low WWR Spaces

The results tables show a surprising finding that reducing furniture heights sometimes has a slight detrimental effect on savings. This was seen in two specific cases: Spaces with Net WWR < 0.40, and spaces with skylights. In all other cases, the effect of lowering furniture heights was always positive, as expected.

The project team researched this result in more detail to get a better understanding of this counter-intuitive result. Our analysis showed that decreasing furniture heights was showing a detrimental effect on savings in mainly the spaces that either had minimal daylight, such as the lowest (10 percent) net window-to-wall-ratios and with windows furthest apart, or punched windows. The result was also noticed particularly in the smaller office spaces, represented by the 20ft x 40ft office template space.

It was concluded from this analysis that the effect noticed here was in part an artifact of the study's analysis methodology. There were many quantum effects that started to interact unpredictably in the small office template, especially when the daylight availability was reduced by both low VLT and small window areas. The placement of the windows interacted with the size of the furniture modules, which interacted with the size of the 8′ x 10′ luminaire analysis units, and further with the rule set for controlling the lights such that the critical task condition was met for each luminaire switching module.

Improvement in energy performance was seen in many cases, with larger window areas and the larger spaces. Overall, given the uncertainty of predictions at the marginal conditions of low WWR and small room size, it is recommend that the condition with low furniture be considered as "no improvement" rather than detrimental to savings. Clearly, savings are possible; however, they exist in more specialized conditions than could be precisely captured in the project's large-grain analysis methodology.

CHAPTER 6: Conclusions and Next Steps

The results from this study provide the answer to the question of how much energy savings potential from daylighting do existing office buildings have. The results also provide information on which building types have the greatest potential for savings, as well as how much can the savings be enhanced with practical, physical improvements made to the office spaces. This section provides a discussion on the results in context with energy savings estimates from other energy efficiency strategies, and the potential to use the results from this study to develop an energy efficiency program for retrofitting existing office spaces with photocontrols.

The project team devised a new method of estimating daylighting for a space using façade templates. The team also developed a method of estimating associated energy savings from dimming or switching photocontrols by creating modified lighting schedules. This approach has the potential to be used to quickly estimate daylighting energy savings for a space, by mapping results from pre-simulated façade templates. This section also provides a discussion on how this new approach can be used for quick energy estimations from daylighting.

6.1 Savings from Office Daylighting Retrofits Compared to Other Programs

The statewide annual energy savings potential from daylighting was a maximum of 458.5 GWh and 184.2 MW of demand savings. While this represents the technical potential of savings from daylighting, it is conceivable that an initial statewide retrofit program that incentivizes the cost and installation of photocontrols, may achieve a 10 percent market penetration in five years, and thus provide 45.9 GWh of energy savings and 18.4 MW of peak demand savings annually.

Energy savings per square foot of building area by building size for all office buildings was 0.70 kWh/sf-yr and demand savings was 0.29 W/sf.

The project team compared estimates of gross energy savings from a number of other sources to provide context for comparison to other energy efficiency strategies for existing buildings. The findings from these comparisons are presented in this section. Certainly many other comparisons are possible beyond the four discussed below.

- The 2006-2008 Energy Efficiency Evaluation Report published (CPUC, 2010) reported annual and lifecycle energy savings by market sector and group. For all energy efficiency measures for indoor lighting in the commercial sector, the report states that 1,090 GWh of annual energy savings, and 235 MW of annual demand savings were achieved (Table 21). At an estimated 10 percent market penetration, an initial office daylighting retrofit program could represent about 4 percent of the statewide 3-yr program energy savings and 8 percent of demand savings.

- According to PG&E's California Multi-Family New Homes, gross committed savings goal for their current 3 year cycle (2010-2012) is 4.6 GWh of energy and 3.94 MW of demand savings. The technical potential of daylighting energy savings for the PG&E territory was 194 GWh. Assuming a 10 percent penetration rate over a five year program, the annual savings would be 19.4 GWh of energy savings and 8.06 MW, which would be about four times that of the CMFNH program energy goal and about two times the demand savings goal.
- For the 2013 non-residential lighting retrofits Title 24 CASE report (California Utilities Statewide Codes and Standards Team, 2011), the statewide estimated annual savings from the proposed code changes that related to Section 131(b) Tuning, Section 131(d) Automatic shutoff controls, and Section 146 Reduction in Lighting Power Densities, is estimated to be a total of 44.2 GWh of energy savings an 4.9 MW of demand savings. At an estimated 10 percent market penetration for an office daylighting retrofit program, the magnitude of energy savings are very similar at 45.9 GWh , but demand savings from the daylighting retrofit programs would be 3.8 times greater at 18.4 MW.
- The Sylvania Lighting Services High Performance Lighting Program, an ongoing 3rd party lighting retrofit program for PG&E, has a published goal of achieving 33.6 GWh of gross annual energy savings, and 8.4 MW of gross demand savings (Sylvania Lighting Services, 2009). The program aims to retrofit efficient ballasts and advanced lighting controls in existing offices and warehouse buildings. At an estimated 19.4 GWh of energy savings and 8.1 MW of demand savings from an office daylighting retrofit program in PG&E territory, the estimated energy savings from a daylighting retrofit program for office buildings only, are about 58 percent of the energy goals and, the demand savings are a match. Since both are office retrofit programs, including savings from photocontrols in daylit areas, there is substantial overlap in the target population for the two estimates.
- The project team provided a very rough estimate of energy savings at the beginning of the project as part of its proposal to the CEC PIER. The team had estimated 69 GWh/yr of energy savings and 14 MW of peak demand reduction using the same assumption of 10 percent market penetration in five years. The final calculated estimate is 45.9 GWh of energy savings and 8.4 MW of peak demand savings. The initial estimates were high by about 33 percent for energy savings and 40 percent for demand savings.

6.2 Daylighting Retrofit Programs

Existing office buildings offer a unique opportunity for energy savings through the use of daylighting. Most offices are designed with windows to admit daylight and provide view to the outdoors as an amenity for a healthy and productive indoor environment. With the addition of photocontrols, energy and demand savings from lighting and HVAC energy use can be obtained at a fairly low cost. The results from this study provide estimates for average annual energy savings from photocontrols in office spaces in California. The results also provide information about which building types have the greatest potential for daylighting savings, as well as how much can the savings be enhanced with practical improvements to the office spaces.

With these results, utility programs can tailor a targeted approach for a daylighting retrofit program that could incentivize the cost and installation of photocontrols and dimming ballasts in office buildings. A recent survey of photocontrols cost conducted for the California Title 24 Codes and Standards Enhancements work (California Utilities Statewide Codes and Standards Team, 2011) found that the cost to purchase and install a switching photocontrol system, was between $350 to $560, and that for a dimming photocontrol system was between $468 to $887. The costs were for a new construction, and for two examples, one with 250sf of daylit zone area and another with about 900 sf of daylit zone area. Costs for retrofits are likely to be slightly higher for extra labor cost. As reported by the study, this represents a significant drop in cost of photocontrols in the last few years.

A daylighting retrofit incentive program should target buildings with the greatest opportunity first. The results show that small office building (< 30,000 sf) have a per square foot energy savings potential that is close to twice that of large office buildings (>30,000 sf). The proportion of large versus small office spaces is different for different utility territories, but at a statewide level, there is about twice as much large office area as there is small office area. Furthermore, results also show that buildings with larger window areas have greater saving potential, such that those buildings with Gross WWR > 0.20 have about 50 percent more savings potential than buildings with Gross WWR < 0.20. Thus an incentive program in a utility territory with a more small office spaces area could target small offices with Gross WWR > 0.20 first, and large offices with WWR > 0.20 next. In a utility territory with more large offices spaces, the incentive program could target spaces with other physical characteristics that show increased energy savings such as private versus open office layout and furniture partition heights, rather than purely window-to-wall-ratios.

Based on results from daylighting improvements, the project team recommends that a retrofit program that incentivizes photocontrols, should also include mandates or incentives for simple improvements to the spaces to enhance energy savings from daylighting, such as replacing ceiling acoustic tiles with high visible light reflectance (85 percent to 90 percent) tiles, painting walls, and replacing existing office furniture with reduced partition heights and/or replacing opaque with transparent panels.

Advanced daylight optimized blinds and light re-directing systems are also potentially an attractive retrofit for existing buildings, but were not included in this study due to technical limitations in the analysis methodology.

This project provides only one side of the retrofit equation: the value of the energy savings benefits. In order get to the next steps for supporting program implementation, the installation costs for all measures should be factored in, depending on assumptions about simple retrofit or major renovation for each project. In addition, the energy impacts numbers from this analysis should be combined with other efficiency measures that might be considered simultaneously, such as occupancy sensors or lighting power density reductions. Ideally, a calculator would be created that would allow a program representative to estimate costs and benefits for a given building site.

6.3 Façade Templates Retrofit Estimator

The façade templates approach provides a new simplified method of estimating daylighting for a sidelit or toplit space. The project team devised this approach to quickly estimate daylighting energy savings for a space, by mapping results from pre-simulated façade templates to corresponding real buildings.

The project team developed 861 façade templates for this study, which were carefully selected to represent the majority of exterior facades conditions found in the CEUS dataset for office buildings. This set of façade templates provides a dataset of annual daylight simulation results for the most common façade types in California office buildings, categorized by climate location, orientation, window type and size, space size, furniture configuration, and so forth. To generate a quick estimate of energy savings for a given building, the closest approximation of façade templates for that building can be identified, and then daylighting results associated with those templates mapped to each space type in the building. Once daylighting results are available for a space, they can be used to identify daylit zones, and create a modified lighting schedule with photocontrols to estimate daylighting energy savings for that space, and then aggregated back up to the building level.

The process described above, which was the methodology for this study, can provide an estimate of annual daylighting energy savings for a given space without the need to run an annual simulation for that space, by appropriately mapping from the real conditions to nearest available façade representation. The process can thus provide an improved estimate of energy savings, with very little investment of time, and without the need for the skill and knowledge needed to run annual daylighting energy simulations.

This simplified approach is likely to have applications for utility programs to estimate energy savings from retrofits, energy audits, daylighting design assistance and design charette tools, and other situations where approximate energy savings estimates are needed.

6.4 Improvements to CEUS

One of the key realizations as a result of this study has been the inadequacy of existing databases such as the CEUS database in providing relevant information to perform a daylighting energy estimation. While CEUS provides a fair amount of detail for estimation of HVAC energy loads, many inputs needed for daylighting estimation were overly simplified or simply missing. The following is a list of poorly defined items that should be improved in the next round of CEUS.

1. **Space Definition:** A space defined in a CEUS eQuest model is an HVAC zone. In most cases this does not correspond to a 'physical space' as defined by floor-to-ceiling partitions, or interior walls. From a daylighting analysis perspective, this is an important limitation. In

office spaces with private offices immediately next to a façade this is likely to create an overestimation of daylighting savings. Also such physical spaces may have different LPDs, which is only captured as an average for an HVAC Zone in an eQuest model.

2. Window layouts: The extent to which daylight spreads across a façade depends on how the windows are laid out on the wall. The eQuest models in the CEUS dataset were designed to capture the total window area per wall in one large window per facade, thus the window layout details are not captured. Using one large window per façade was a strategy employed to reduce modeling time, which loses minimal accuracy for an HVAC analysis, but loses significant accuracy for a daylighting analysis.

3. **VLT of Windows**: The project team found that about three quarters of the windows in the office models had been assigned a VLT of 0.90, clearly an incorrect value. This unusually high number meant that appropriate information about window tint (or VLT), had not been captured in the eQuest models. This is the most severe limitation of the current CEUS dataset as it would greatly overestimate daylighting compared to reality.

4. **Exterior Obstruction**: It's common knowledge that most windows and façades have some sort of exterior obstructions to incident solar radiation and daylighting. These are usually trees or other neighboring buildings. Leaving out those obstructions from a HVAC design view point, may be acceptable, although it probably overestimates cooling loads and underestimates heating loads. However from a daylighting perspective, this clearly impacts daylight availability in a space, and also overestimates the need for blinds operation. The CEUS on-site surveys and eQuest models do not currently capture information on the exterior obstructions.

5. **Window Blinds/Shades (Interior Attachments):** Blinds and shades have only a limited impact on HVAC energy use. Blinds can reject a portion of solar radiation incident on a window, but the rest is absorbed and remains in the conditioned space. However, a model without blinds or shades, will create a very unrealistic daylighting model. Such a model will over predict available daylighting in a space. It hence becomes very important to not only model blinds and their light transmittance properties, but also to model a blinds operation schedule.

6. **Interior Surface Reflectance**: Similar to furniture, interior surface reflections, or color of the floor, wall and ceiling too has no significance in a model to predict building HVAC and scheduled lighting energy use. But for daylighting analysis, interior surface reflectance plays an important role in determining illuminance levels in the space.

7. **Furniture Layout and Height**: Furniture has limited or no importance in a model to predict building HVAC and scheduled lighting energy use, and hence was not captured in the CEUS on-site surveys. However for daylighting analysis of a space, this becomes a very important factor. A space with 60" high furniture is likely to have limited daylight penetration from an external façade, but the same space with 45" or 30" high furniture will have a much deeper daylight penetration.

6.5 Improvements to Code Compliance and Professional Simulation Tools

Simulation software, both research grade and professional grade products, both publically and commercially funded, need the ability to model daylighting accurately, allowing designers and code compliance professionals to estimate energy savings of various design options. Most current simulation software, based on either DOE2 or Energy Plus, use a very simple split flux method of estimating daylighting. Daylighting simulation software that use a ray-tracing or radiosity method, such as DaySim, 3D Studio Max, and AGI allow a more accurate daylighting simulation. The Dynamic Radiance approach developed for the Daylight Metrics project, under the Daylighting Plus program, provides a viable alternative to the default split flux method. The approach was used extensively in this study and the project team developed a method to input and output results to a whole-building energy simulation software such as DOE2 or Energy Plus.

The Dynamic Radiance Approach is currently a set of scripts available to Radiance users, but can only be used successfully by an 'expert' Radiance user. The Dynamic Radiance Approach would greatly benefit from a graphic users' interface (GUI) and a users' manual, and finally would be most useful if incorporated into a whole building energy simulation software such as DOE2 or Energy Plus.

6.6 Improvements to ASHRAE Benchmark Buildings

An important finding of the Daylight Metrics project (Heschong, 2011), which was echoed in this study, has been the importance of accurate modeling assumptions for daylighting. Simulation models have been historically created and used to estimate HVAC energy use, and the level of detail employed in these models has been sufficient to estimate HVAC loads. As discovered in this study using the CEUS dataset of eQuest (DOE2) models, details that have a significant impact on the daylighting of a space were either poorly incorporated, or missed all together. Similarly, the set of Energy Plus models used by ASHRAE as benchmark buildings to determine the impact of code changes are perhaps appropriate for understanding thermal comfort and heat flow analysis, but have major limitations in terms of understanding daylighting performance. The modeling methodologies have limitations on a number of fronts:

1. **Blinds Assumptions:** The models use simplified assumptions about blinds operation and blinds light transmittance. Without a fairly nuanced dynamic operation of blinds or shades, annual daylight illumination cannot be predicted accurately. The accompanying Daylighting Plus project report on Daylight Metrics (Heschong, 2011) provides further details about the extent to which daylight is affected by modeling assumptions of blinds.

2. **Exterior Obstructions:** A key finding from this study was that about 60 percent of office buildings in California have some level of obstruction from trees, and 16 percent had either heavy or light urban obstruction, or obstruction due to other buildings. There is a complete lack of exterior obstructions in all models. By not accounting for these obstructions, the cooling loads are getting underestimated, while the daylighting is getting overestimated.

3. Interior Space and Furniture Layouts: While interior walls and furniture have little or no impact on HVAC loads, they have a significant impact of daylighting. Modeling furniture was a key factor in this study, which allowed for the study to determine the impact of furniture heights. The study found that furniture heights can have up to a 16 percent impact on savings estimation.

While further research is needed on all three fronts described above, this study provides a first attempt at better modeling assumptions for daylighting and their impacts on overall energy savings.

6.7 Research Needs

The key research needs identified from this study pertain to better assumptions for modeling to estimate daylighting energy savings. For daylighting to be further employed as an energy efficiency strategy, it is critical to have further research on the following topics.

Blinds Operation: Better data on blinds operation, by orientation, space type, blinds type, pattern of sun penetration, interaction with view, and automated control operations is needed to develop predictive models for daylighting simulation. Blinds operation has been shown in the Daylight Metrics study (Heschong, 2011) to be a key factor in the determination of daylight availability. The motivations for blinds operation are complex, and have important impacts on many building systems.

The blinds operation assumption used in this study were inherited from the Daylight Metrics study that developed a set of simple but consistent assumptions about blinds operation. These were based on the best available information at the time. It is understood, however, that the operation of blinds is far more variable than those simple assumptions.

Exterior Obstructions: A key finding from this study was that about 60 percent of office buildings in California have some level of obstruction from trees, and 16 percent had either heavy or light urban obstruction, such as obstruction due to other buildings. Exterior obstructions hence have a significant impact on building energy use. They affect not only daylighting, but also the heating and cooling loads.

Simulation models are typically modeled having no exterior obstruction and a few very limited studies in the past (Carmody, 2004) have attempted to either quantify, or develop a standard obstruction model for exterior obstructions. There is a need to better understand type, shape and extent of exterior obstructions on buildings.

This study, using CEUS data, collected information about tree shading and urban shadings, and developed a set of obstruction models that were applied to the template spaces. However, as this was not the primary focus of the study, the study team was not able to devote extended effort into data collection. Further data collection is required to get a better understanding of the extent of shading and visible obstructions that trees and other buildings provide. Also, more effort if required to develop or refine the exterior obstruction models that were created in this study.

Savings Estimate for Other States and at National Level: This study provides an estimate for daylighting savings potential for the state of California, using the dataset from the California Commercial End-Use Survey. While this provides useful savings estimates for California, the savings cannot be easily extrapolated for other states or the country.

The CEUS dataset provides a good range in terms of building types and space and façade geometries, which are not likely to be much different for other states or the rest of the country. However, to generate savings estimates for other states, the simulation will need to be run using a different set of climate files than those used for California in this study. Additionally research will also be required to collect building type data and develop expansion weights for a different building population.

GLOSSARY

BDL	Building Description Language
BSDF	Bi-Directional Scatter Distribution Function
CBECS	Commercial Buildings Energy Consumption Survey
CEUS	California Commercial End-Use Survey
DEER	Database of Energy Efficiency Resources
fc	foot candle
IOU	Investor Owned Utility
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
NRNC	Non-Residential New Construction
VLT	Visible Light Transmittance
WWR	Window to Wall Ratio

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APPENDIX A:
Façade Templates

Façade Templates were created as part of the simulation approach developed for this study. A set of 35 façade template were first developed to span all possible options with the following four variables:

1. Ceiling Height: 10ft and 8ft
2. Window Type: Grouped, Punched, Strip and Curtain Wall
3. Head ht - Ceiling ht differential: 0ft and 2ft
4. Net WWRs: 10 percent, 26 percent and 52 percent

Then those façade templates that represented less than 100 instances in the dataset were either eliminated or substituted. This appendix provides scaled drawing for each of the 35 façade templates designed for use as façade templates in the study. The facades in these figures with the red dotted outline and an "X" mark were the ones eliminated or substituted due to low or no representative population. Note that the set of façade templates for "8 ft ceiling height with 2.5 ft head ht. - ceiling ht. differential" were all eliminated, and hence not shown here. A 100 percent Net WWR is only possible with curtain wall.

Figure 16: Grouped Windows: 10ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

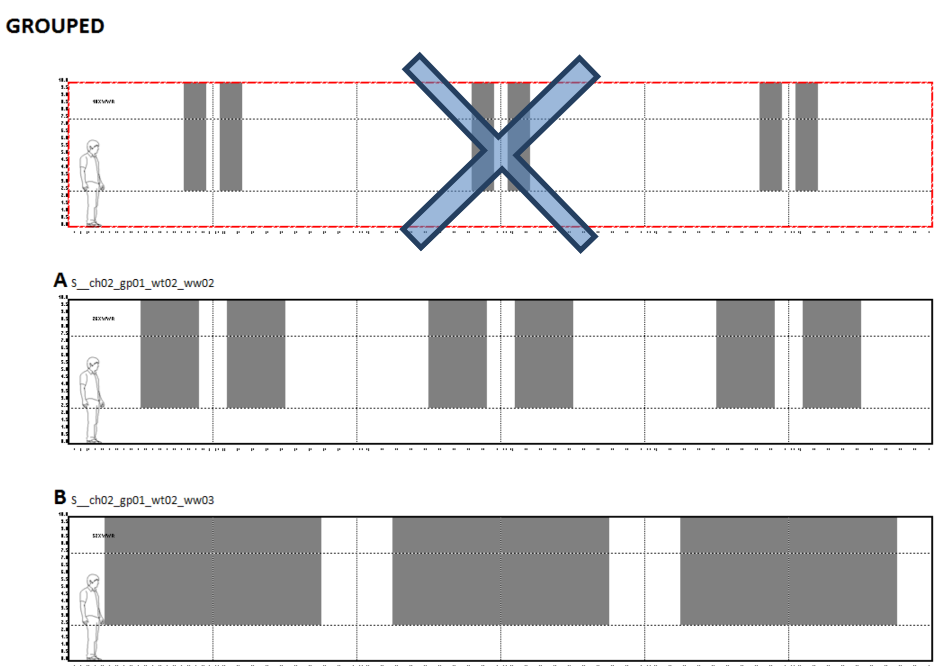


Figure 17: Punched Windows: 10ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

PUNCHED

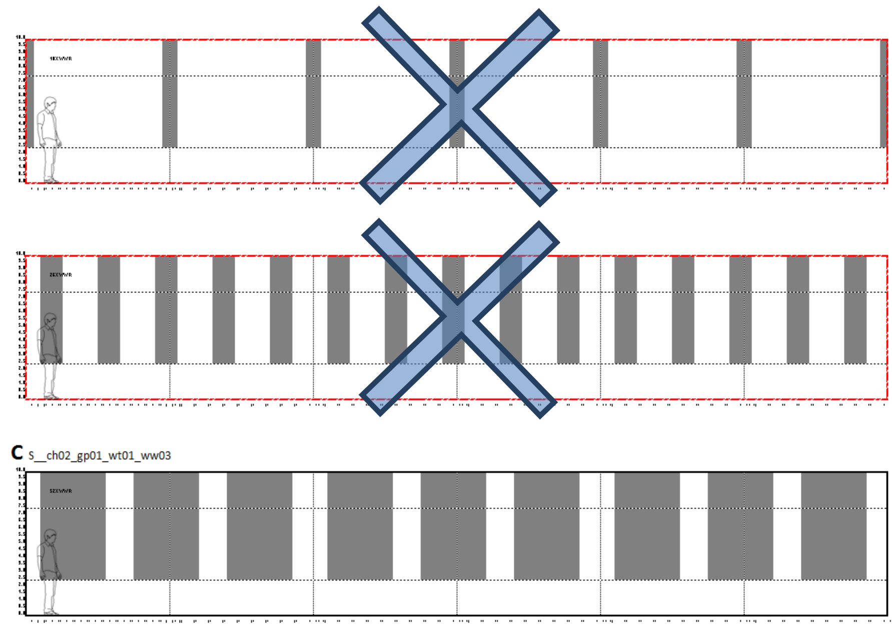


Figure 18: Strip Windows: 10ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

STRIP

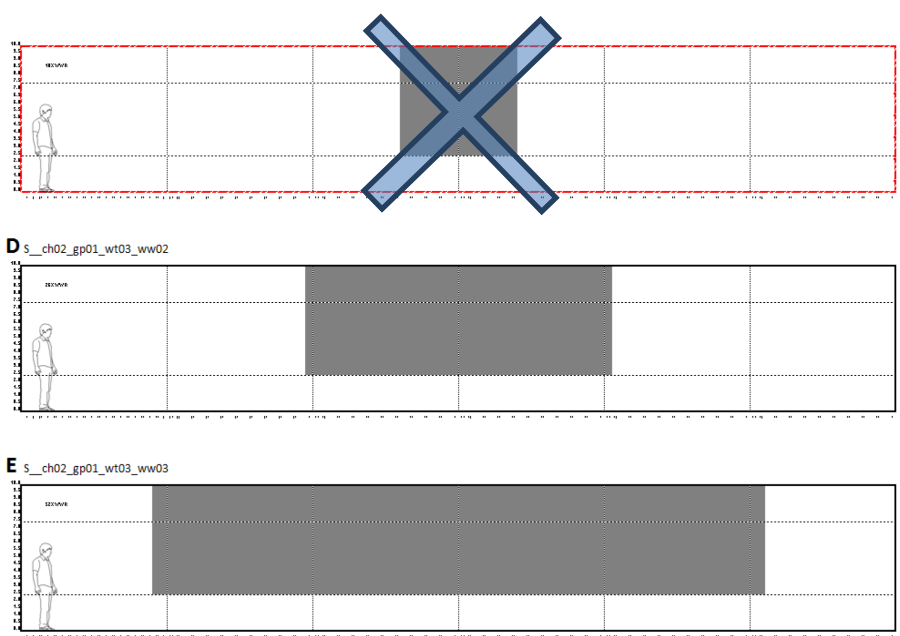


Figure 19: Curtain Wall: 10ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

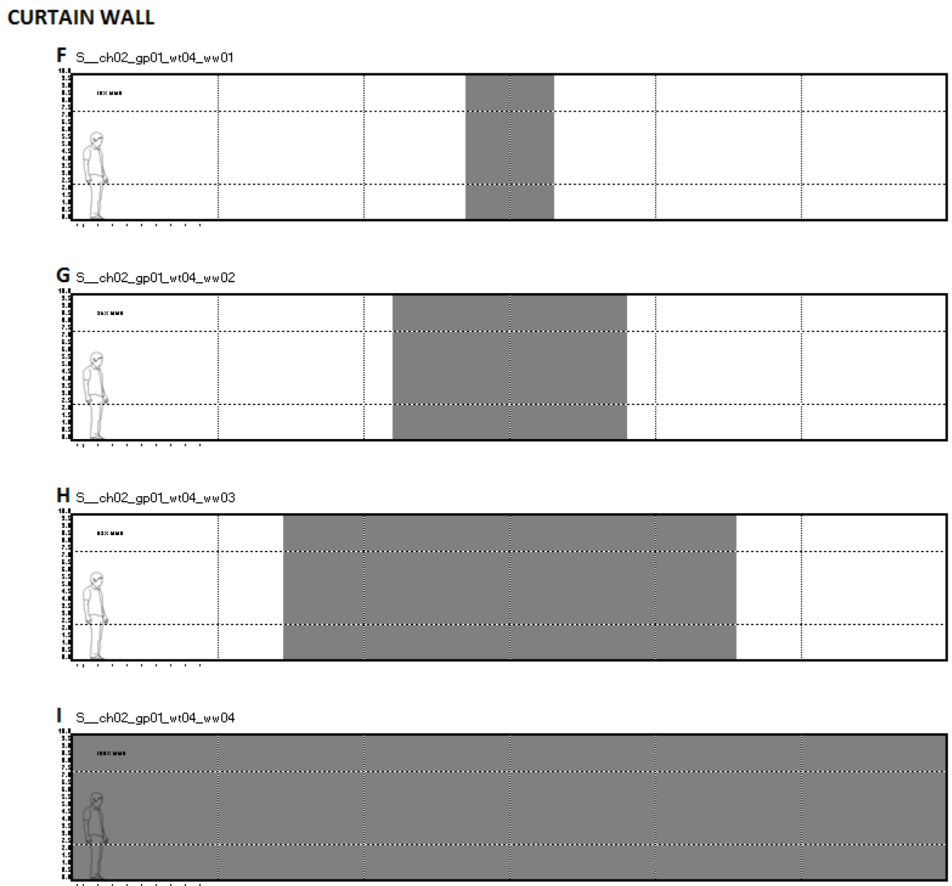


Figure 20: Grouped Windows: 10ft ceiling Ht, 2.5ft head - ceiling ht, 10%-26%-52% WWRs

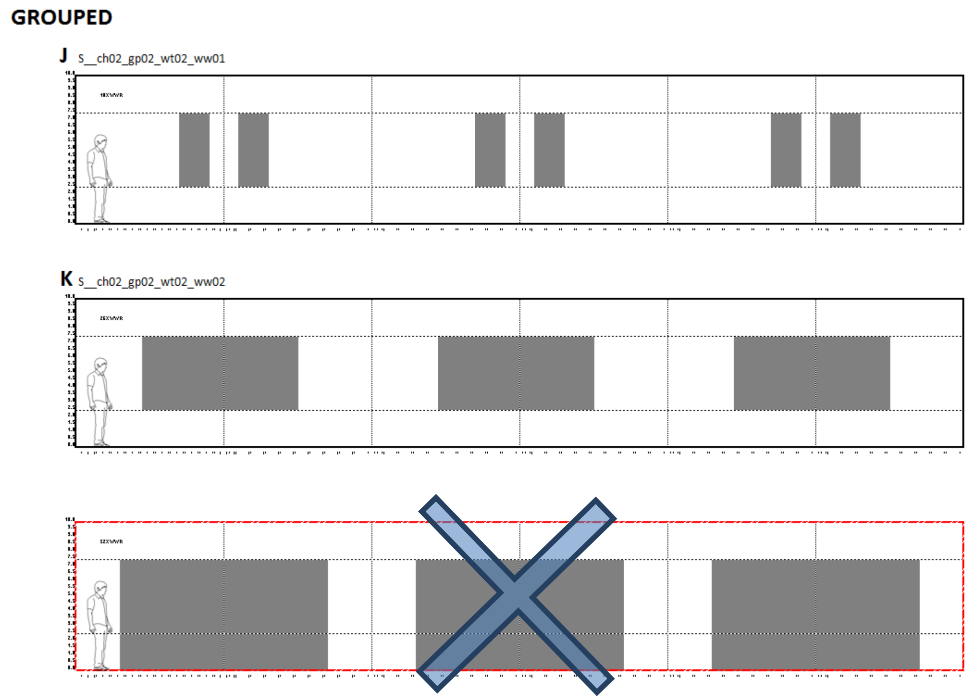


Figure 21: Punched Windows: 10ft ceiling Ht, 2.5ft head - ceiling ht, 10%-26%-52% WWRs

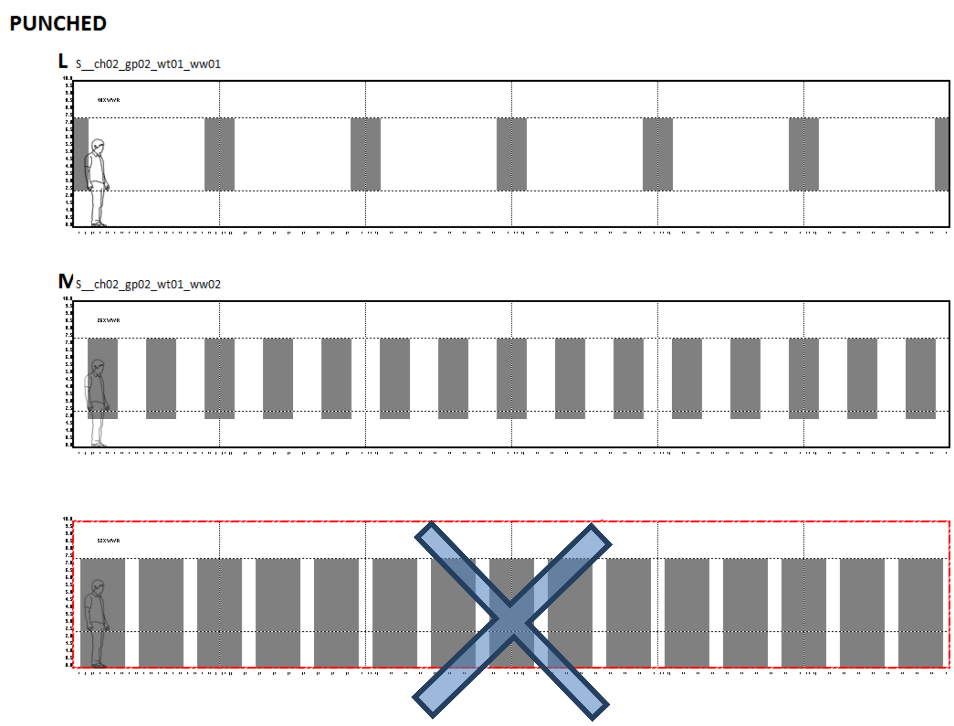


Figure 22: Strip Windows: 10ft ceiling Ht, 2.5ft head - ceiling ht, 10%-26%-52% WWRs

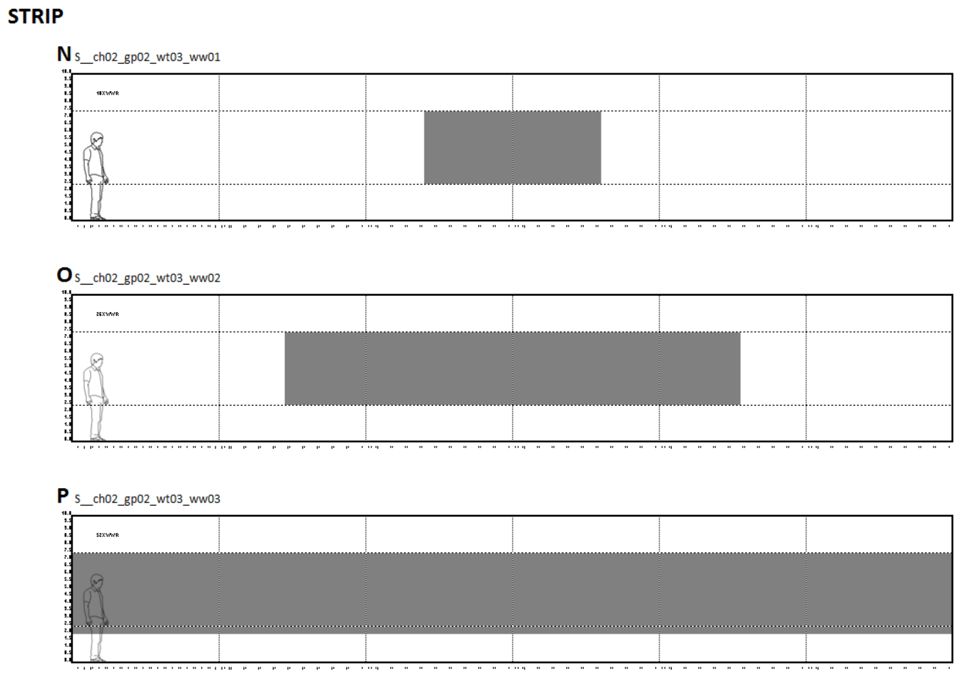


Figure 23: Grouped Windows: 8ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

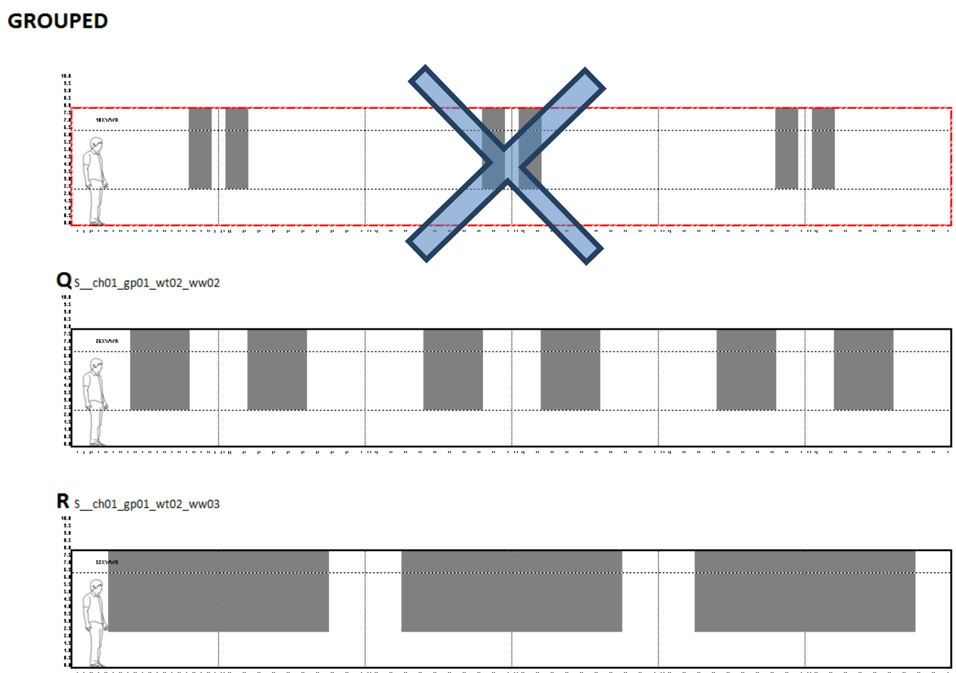


Figure 24: Punched Windows: 8ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

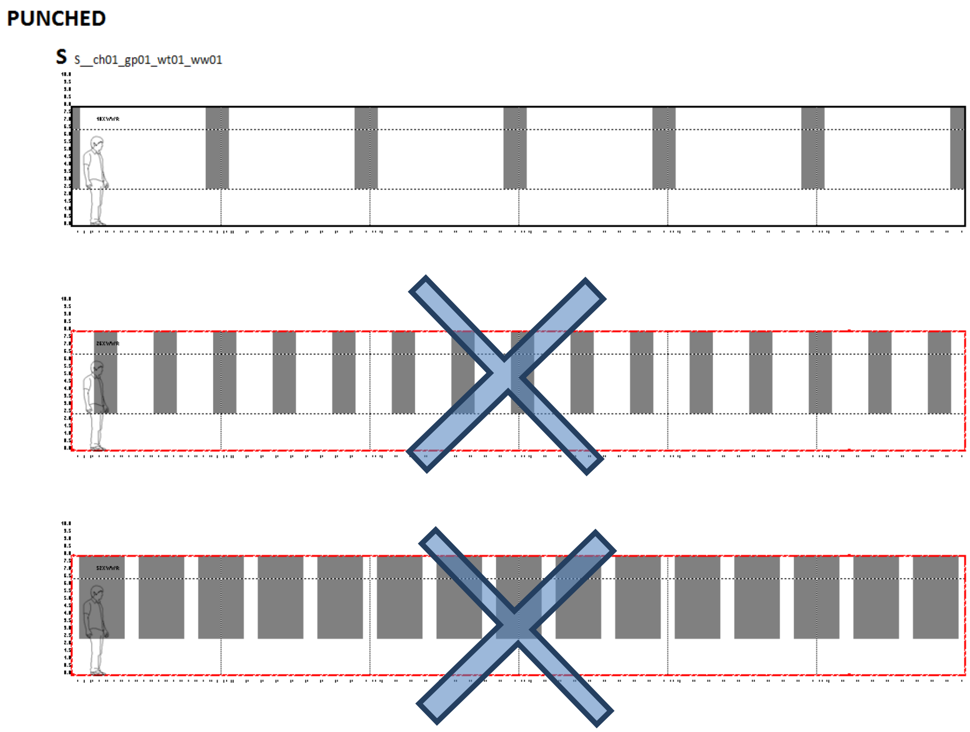


Figure 25: Strip Windows: 8ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs

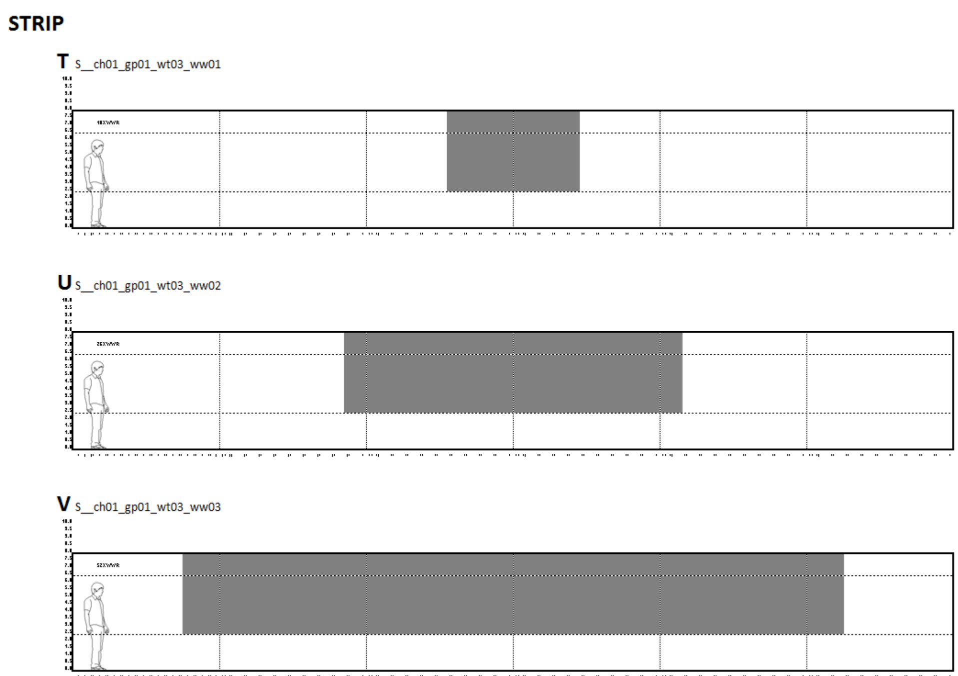
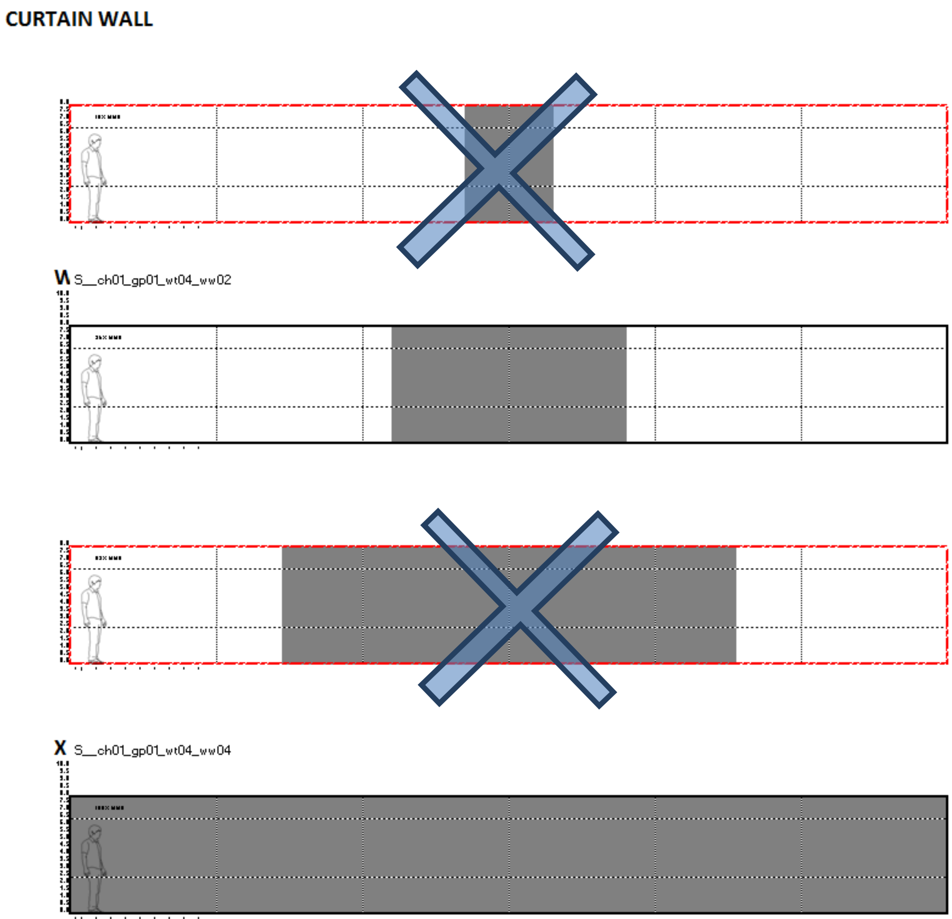


Figure 26: Curtain Wall: 8ft ceiling Ht, 0ft head - ceiling ht, 10%-26%-52% WWRs



APPENDIX B: Space Activity Types

The CEUS dataset classified all spaces within the 536 office premises by space types. The project team mapped these space types to those most likely to be amenable to daylighting controls. Spaces likely to have atypical partitions, demanding visual tasks requiring more than 300 lux, inappropriate for automatic photocontrols, or very low occupancy were eliminated from the analysis.

The table below provides office space activity, statewide percent floor area and keep/eliminate decision.

The space activity types are sorted by percent floor area. The total percent of available floor area from the CEUS dataset which was eliminated here, is 9.5 percent

Table 31: Space Activity Type with Percent Floor Area and Keep/Eliminate Decision

Space Activity Type	Percent floor area	Keep / Eliminate
Office (General)	50.81%	Keep
Office (Open Plan)	10.38%	Keep
Office	10.05%	Keep
Laboratory, Medical	2.83%	Keep
Corridor	2.30%	Keep
Other Use	2.30%	Keep
Office (Executive/Private)	2.15%	Keep
Bank / Financial Institution	1.88%	Keep
Medical and Clinical Care	1.85%	Keep
Kitchen and Food Prep	1.44%	Eliminate
Conference Room	1.29%	Keep
Storage (Unconditioned)	1.20%	Eliminate
Mechanical/Electrical Room	1.13%	Eliminate
Storage (Conditioned)	1.08%	Eliminate
Dining Area	1.06%	Keep
Restrooms	0.84%	Eliminate
Lobby (Reception/Waiting)	0.78%	Keep
Retail / Wholesale Showroom	0.63%	Eliminate
Library (Stacks)	0.62%	Eliminate

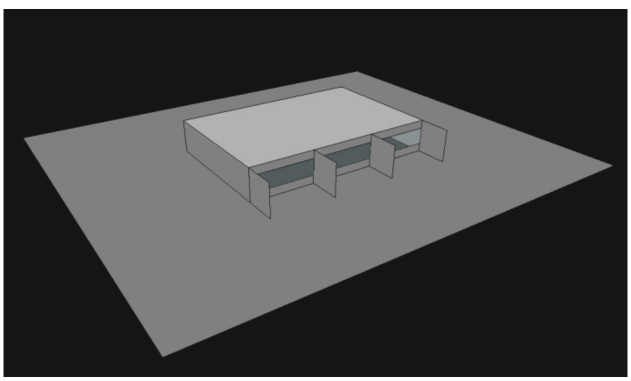
Space Activity Type	Percent floor area	Keep / Eliminate
Courtrooms	0.59%	Keep
Lobby (Main Entry / Assembly)	0.54%	Keep
Exercising Center / Gym	0.45%	Keep
Auditorium	0.45%	Eliminate
Comm/Ind Work (Gen, High)	0.45%	Eliminate
Classroom / Lecture	0.41%	Keep
Convention / Meeting Center	0.40%	Keep
Comm/Ind Work (Gen, Low)	0.29%	Eliminate
Police / Fire Station	0.28%	Eliminate
Library	0.21%	Keep
Lobby	0.21%	Keep
Comm/Ind Work (Precision)	0.21%	Eliminate
Storage	0.21%	Eliminate
Residential (Single Fam.)	0.18%	Eliminate
Locker and Dressing Room	0.12%	Eliminate
Comm/Ind Work	0.10%	Eliminate
Theater (Motion Picture)	0.09%	Eliminate
Auto Repair Workshop	0.06%	Eliminate
Copy Room (photocopy eq)	0.04%	Eliminate
Mall, Arcade and Atrium	0.04%	Eliminate
Dry Cleaning (Full Srvc)	0.03%	Eliminate
Casino / Gaming	0.01%	Eliminate
Exhibit Display / Museum	0.01%	Eliminate
Theater (Performance)	0.01%	Eliminate

APPENDIX C:
Exterior Shading Models

The project team undertook an exercise to come up with a standard method for simulating urban shading conditions. It was desired to create a simple set of obstructions that could be applied to a template to imitate either light or heavy urban shading, as identified by the analysis of the actual site conditions for the 536 CEUS sampled buildings.

All shading models that were simulated and their associated daylight autonomy plots are presented in this appendix in Figures 27 through 33.

Figure 27: Shading Model a1



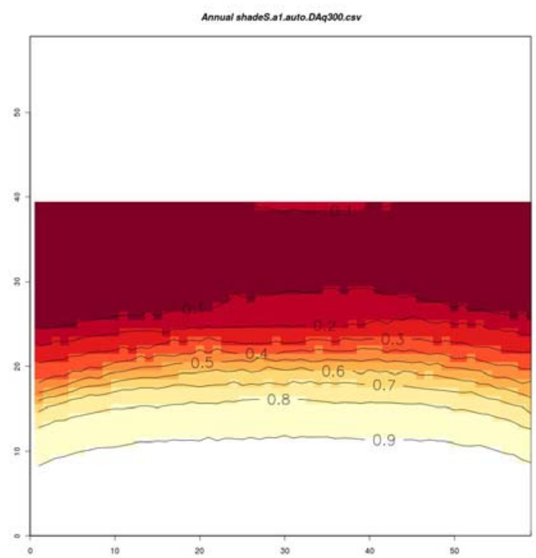


Figure 28: Shading Model a2

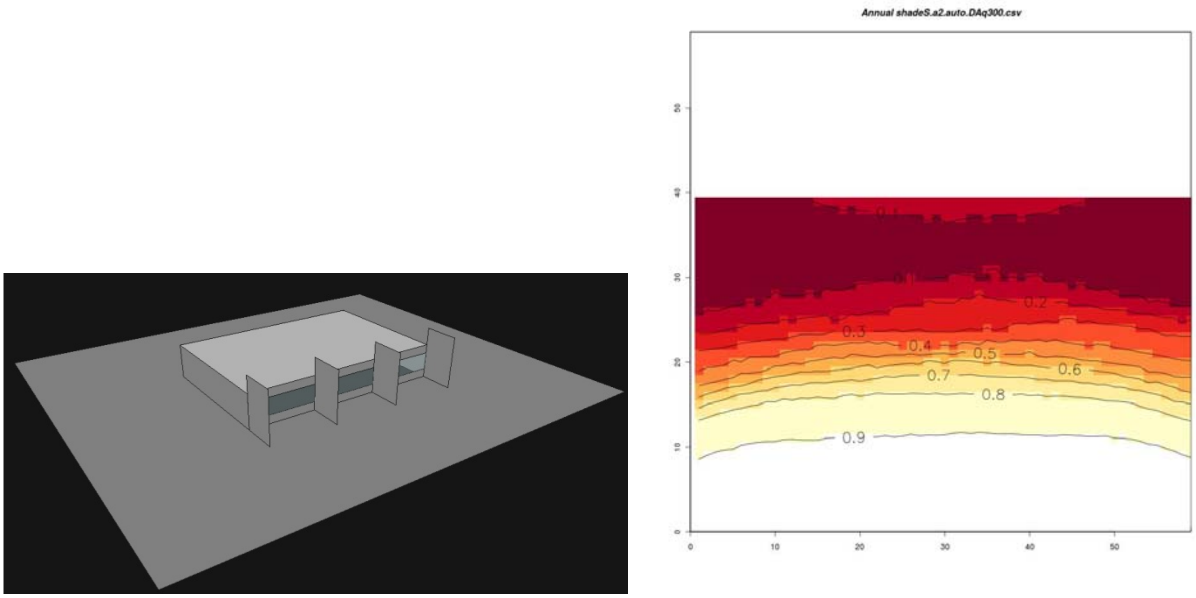


Figure 29: Shading Model a3

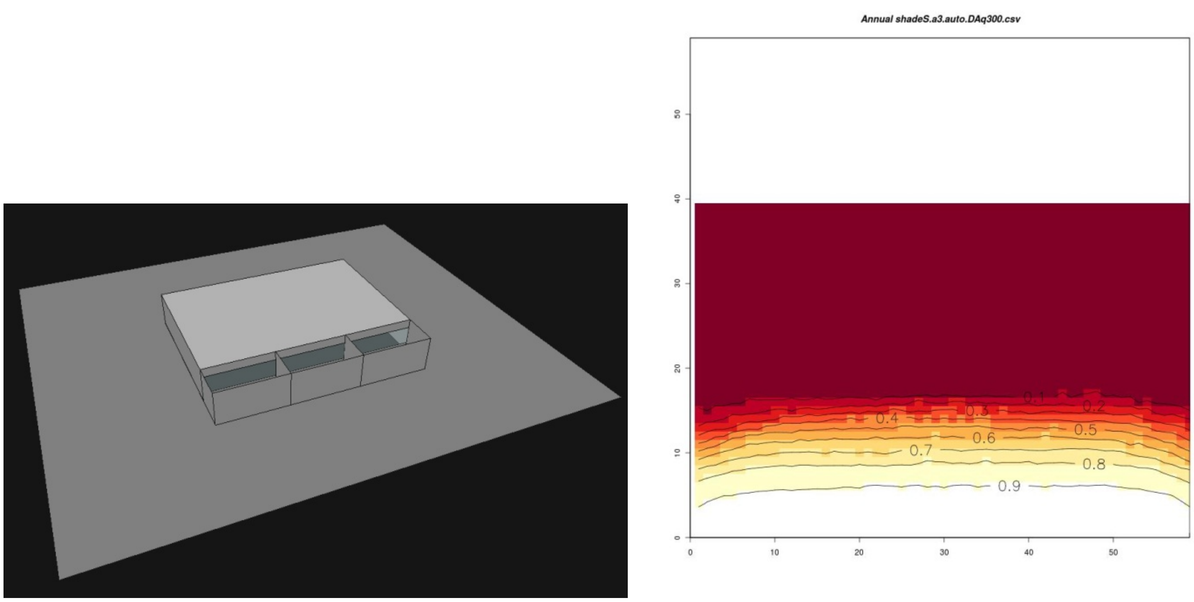
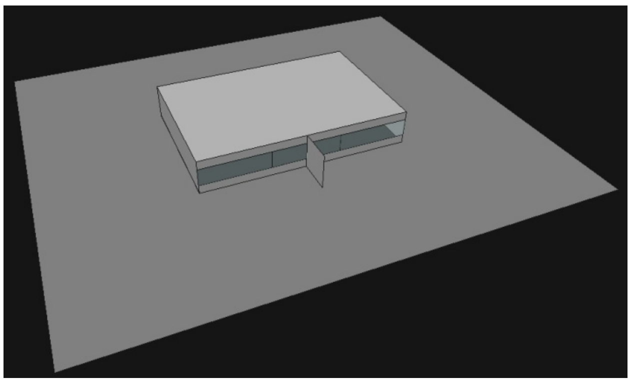


Figure 30: Shading model b1



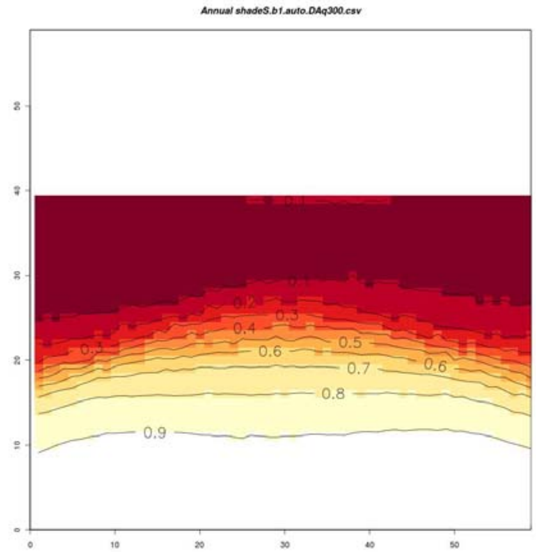
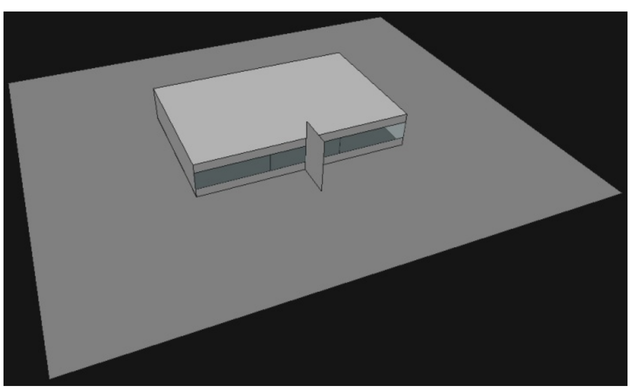


Figure 31: Shading model b2



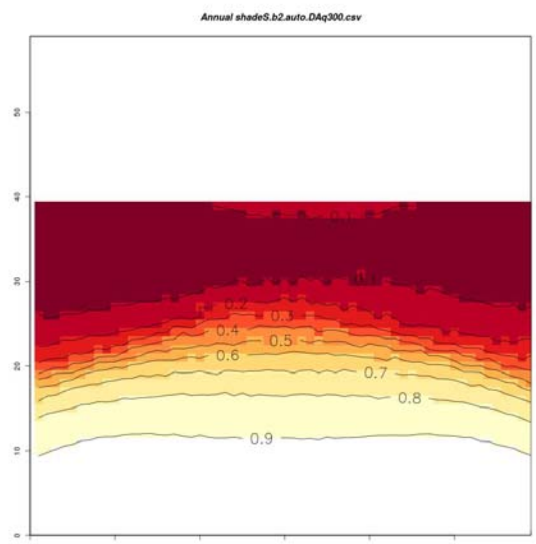
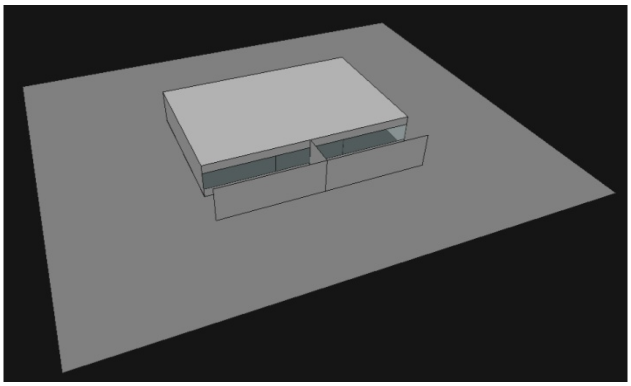


Figure 32: Shading model b3



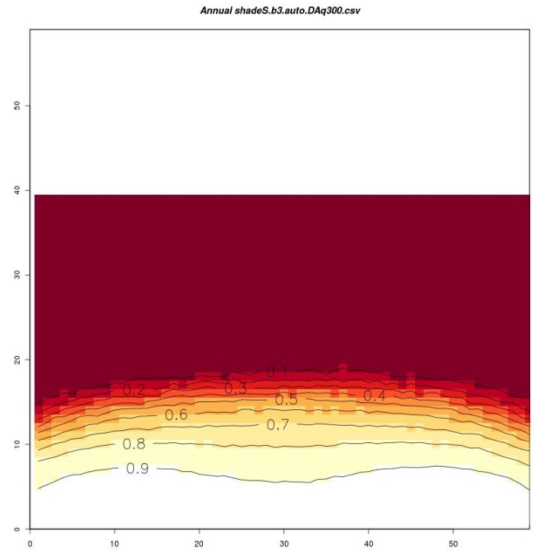
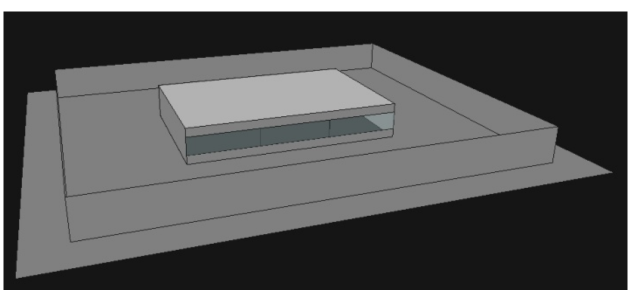
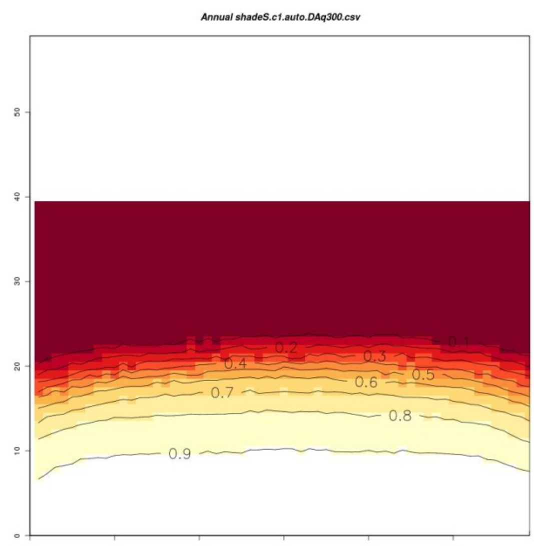


Figure 33: Shading model c1





APPENDIX D: Dynamic Radiance SimBuild 2010

Dynamic Radiance – Predicting Annual Daylighting with Variable Fenestration Optics Using BSDFs

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ABSTRACT

Existing annual daylight simulation software fall short with respect to variable fenestration optics that change interior daylight distribution with sun position and/or operating schedule, thus limiting the ability to compare the performance of advanced fenestration systems. Many of these window or skylight systems can be described efficiently as a bidirectional scattering distribution function (BSDF), which characterizes their flux output as a function of input for a particular configuration. In this paper, we describe a new method that employs measured or simulated BSDFs to permit fast, matrix-based annual daylighting calculations. The matrices themselves are precomputed by Monte Carlo ray-tracing in a modified daylight coefficient approach we call *Dynamic Radiance*. The inner time-step loop then consists of multiplying the desired sky luminance vectors against three matrices in the general case, where a separate BSDF matrix permits dynamic fenestration control strategies. In this paper, the authors describe their implementation of the Dynamic Radiance method and demonstrate its application to a set of 61 real spaces modeled for a research project to determine new daylight metrics. We present results from these simulations and discuss advantages and limitations of the new approach.

Introduction

It is well understood that energy savings and electric demand reduction potential of daylighting is substantial. However, accurately predicting daylighting at an hourly time-step, for an annual simulation, is not a simple task. This was the task at hand for the Daylight Metrics Project [Heschong et al. 2010, Saxena et al. 2010], a reseach project to develop a set of simulation-based metrics to describe daylighting in architectural spaces. The simulation task required annual daylighting simulations for 61 surveyed spaces in six cities across the United States.

Initially a research version of *DaySim DDS* version 2.4 [Bourgeois et al. 2008] was choosen to perform the annual simulations, as it would provided the most modeling accuracy and supported parametric studies. However, mainly due to limitations in *DaySim's* modeling assumptions for window shadings such as blinds and fabric shades (hereon called blinds for brevity), the project team decided to use an alternative progam. While *DaySim* had the ability to operate blinds according to a solar trigger, it was limited to one schedule for all blinds in a given space, irrespective of their orientation. Furthermore, simplified assumptions of blinds light transmittance (20% diffuse, 0% direct) were found to be too simplistic. While *DaySim 2.4* does support the simulation of blinds explicitly [Reinhart et al. 2001], that approach was not used due to additional demand on computation-time. Changes were made to the research vesion of *DaySim 2.4* to enable more than one blind schedules, ultimately, achieving full functionality for the new blinds operation and output functions in *DaySim* was found to be beyond the resources of the project team.

Considering many alternatives, the project team eventually decided to commission development of a new annual simulation approach using Radiance. This approach, which for the purposes of this paper we call *Dynamic Radiance*, would build on *DaySim's* achievements and use a similar daylight coefficient methodology. The Dynamic Radiance method provides the desired blinds-operation functionality, blinds light transmittance, and data ouput. It also adds an important new capability—the ability to model variable fenestration optics that change interior daylight distribution with sun position and/or operating schedule (dynamic fenestration performance).

BI-directional scatter distribution functions (bsdf)

Central to this capability of modeling dynamic fenestration performance, is the use of Bi-directional Scatter Distribution Functions or BSDFs.

A full BSDF, as defined for WINDOW 6, consists of a full Klem sample, or a 145x145 matrix, defining light transmittance through a fenestration assembly. Incoming light striking the exterior surface of the assembly is represented through 145 exterior vectors. Similarly, light transmitted by and exiting the assembly is represented through 145 interior vectors, as shown in Figure 1. A BSDF file defines coefficients (c ≥0) to allocate light from each exterior vector to each interior vector. These coefficients are stored in a 145x145 table. Each columns represent a single exterior vector, while each row represents a single interior vector. The light transmitted into the space on any one interior vector is given by Eq. (1) below

$$I_j = \sum_{k=1}^{145} c_{jk} E_k \qquad (1)$$

Where:

E_k = light along exterior vector k
I_j = light along interior vector j
c_{jk} = coefficient relating I_j to E_k which is stored in the cell located in column k, row j of the BSDF

Our implementation of the Dynamic Radiance method utilizes BSDF files to represent fenestration assemblies consisting of the glazing and window coverings. Previous research has shown BSDF data provides acceptable resolution for simulating complex fenestration assemblies [Konstantoglou et al, 2009]. Further discussion of the file format is available from LBNL [Jonsson, 2009; Fernandes, 2006].

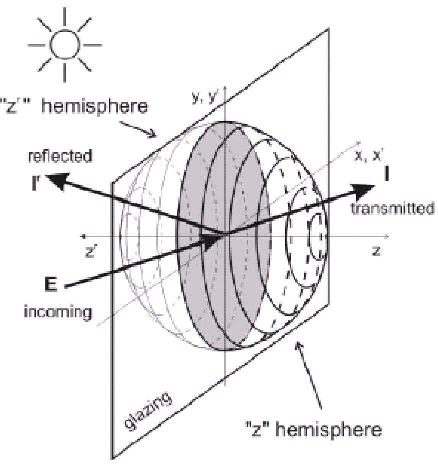

Figure 1: Schematic Diagram representing interior and exterior vectors of a BSDF [Fernandes, 2006]

Dynamic Radiance

Radiance is a lighting simulation and rendering system that was first released by the Lawrence Berkeley National Laboratory in 1989, and has undergone continuous modification and improvement since. Now in its 20th release, *Radiance* 4.0 includes the ability to predict the performance of complex window fenestration systems, defined as the BSDFs just described. To be clear, there is no identifiable program called “Dynamic Radiance.” We have merely created a set of custom scripts and Makefile’s that apply the tools already present in *Radiance* 4.0. The method we are calling Dynamic Radiance is not distributed separately, does not have a user interface, and would have to be substantially modified for a different set of building analyses. The basic tools we will introduce, **rtcontrib**, **genklemsamp**, **genskyvec**, and **dctimestep**, are all part of *Radiance* 4.0, and we are using them to illustrate this overall approach, which we call Dynamic Radiance.

Figure 2: A full simulation using a BSDF on a window with venetian blinds that took 17 hours to generate

In a more traditional mode, the BSDF is used in *Radiance* to represent a window as a "light source" in a backwards ray-tracing calculation of interior illumination. This requires the use of the *Radiance* **mkillum** program, which has been able to interpret BSDF files since the last release. Using this process, high-quality renderings may be obtained as shown in Figure 2, which took 17 hours to generate on a single processor. However, since daylight is a dynamic phenomenon, creating a view of a single point in time is of limited use, and we would prefer a collection of renderings or animations showing how our environment reacts to changing sky conditions. Ideally, we would plot this information over an entire year based on appropriate weather data. In the case of an operable shading system, we may even wish to compare different control algorithms as part of our analysis. If it takes hours to evaluate each time step, this type of annual daylight simulation would be impractical and forbidden to us.

In the past two decades, researchers have been exploring *daylight coefficients* as a means to faster annual calculations in complex spaces [Reinhart, Mardaljevic, etc.]. In this approach, the sky is subdivided and the connection or form factor between sky patches and interior illuminance values (typically) are computed. Since light is linear, it is then a simple matter to multiply the sky luminance values for a particular condition by these coefficients and sum them together to obtain the desired, corresponding interior illuminances. This can be expressed as a matrix equation whose input is the sky vector corresponding to patch luminances at a particular time, and after passing through our daylight coefficient matrix, gives us a vector of predicted illuminance values:

$$\vec{\mathbf{i}} = \mathbf{C}\vec{\mathbf{s}} \qquad (2)$$

Where:

i = resultant illuminance vector (N values)
C = daylight coefficient matrix (N rows by M columns)
s = sky luminance vector (M patch values)

The difficulty we face applying this technique to complex fenestration is two-fold. First, the calculation of the matrix **C** becomes intractable when the interactions at the window involve multiple reflections. Second, in the case of an operable shading system, we would like to be able to modify **C** as we adjust the system, calculating a different version of it for each shade position. This only exacerbates the first problem. What we need is a reformulation of the problem, which allows for the easy substitution of different shading conditions as BSDF's, and also factors the original **C** matrix into more easily calculated components. This is the revised formulation we use in our Dynamic Radiance method:

$$\vec{\mathbf{i}} = \mathbf{VTD}\vec{\mathbf{s}} \qquad (3)$$

Where:

V = a "view matrix" that defines the relation between measurements and exiting window directions (N rows by K columns)
T = the transmission portion of the BSDF (K rows by L columns, usu. K = L)
D = the "daylight matrix" that defines the relation between incoming window directions and sky patches (L rows by M columns)

The **i** and **s** vectors are the same as above; we have simply factored the **C** matrix into three component matrices. The transmission matrix **T** is given as input, so all we really need to compute are the **V** and **D** matrices. For both problems, we employ the *Radiance* **rtcontrib** program.

The rtcontrib Program

Radiance performs its lighting calculations by following rays backwards from the point of measurement and into the scene in search of illumination sources, which are specified as input along with the scene's geometry and materials. The basic **rtrace** tool takes a ray origin and direction for example, and computes its radiance (the radiometric equivalent of luminance) by following the ray into the scene to see what it intersects. If the ray intersects a diffuse surface, for example, additional rays are spawned to the light sources to determine the surface illumination, whereby the outgoing radiance can be determined from reflectance. (The full calculation is a bit more complicated, involving multiple diffuse reflections and so on.)

What if we wanted to know how the outgoing radiance would change as a function of light source intensities? Say we have multiple, dimmable fixtures, which we wish to control continuously to optimize lighting in our space. Recomputing an entire image of radiance values, for each pixel corresponds to at least one ray, would be rather time consuming. It would be better and faster to compute one image for each light source, then add them together as components in our final result. Many people have taken advantage of the linearity of light to do exactly this, but with **rtcontrib**, we have an even more efficient route to such a solution.

Recomputing an image multiple times with different light sources involves many of the same ray intersections with surfaces, especially in the case of multiple diffuse interreflections. We can short-cut this process by computing our multiple images in a single step! We simply identify each light source in our scene that corresponds to a desired image, and **rtcontrib** does the rest. Moreover, we can subdivide exitant directions from our light sources, thereby allowing us to modify luminaire spatial output distributions. In applications such as directable theater lighting instruments, this would be an obvious advantage, but in our case, we want to know how different light output from our windows affects the interior illumination, which is the **V** matrix in the equation above.

Computing the View Matrix (V)

The view matrix **V** defines the relation between a particular set of sensors and a window group. The sensors may be a set of illuminance points on the workplane or ceiling, or an entire image of radiance directions from a particular viewpoint. The window group may be a single opening or a skylight, or a portion of a segmented window, or multiple windows all facing the same direction. The decision of how to group windows may be dictated by geometry, or the desire to control shading (such as blinds) independently, or other factors. At a minimum, we need a separate group for each window orientation, since we use the surface normal to anchor our directions. Figure 3 shows the contributions from the leftmost bay window of one of our test models, assigning a different random color to each of 145 output directions. Each bay window would require a different group, since they have independent orientations, but the two windows to the left of the bay could be placed into one group if desired.

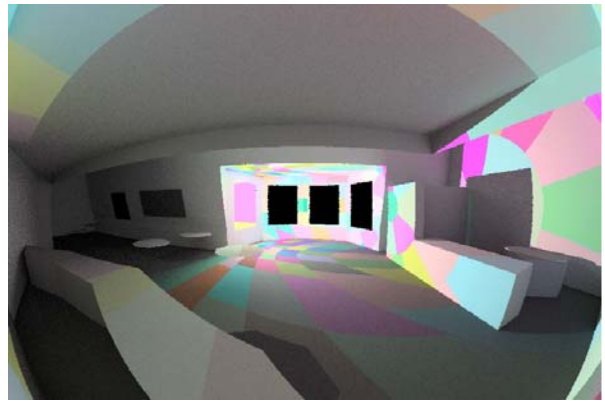

Figure 3: A rendering showing the different output directions for a single window group

Because **rtcontrib** permits output based on direction and material grouping, a single run can produce all the desired **V** matrices corresponding to every window group, and this calculation needs to be done only once per unique interior geometry. Depending on the length of the desired **i** sensor vector, scene complexity, and window groups, this step takes anywhere from under a minute to several hours. The scene above took about three hours to compute for 145 directions for each of 7 window groups feeding 426,400 sensors (pixels in an 800x533 image). That's about 426 million coefficients, which we packed into 1015 Radiance pictures (662 MBytes).

The advantage is that a final image for a particular shade and sky condition can be computed in about 10 seconds. Figure 4 shows one such time step.

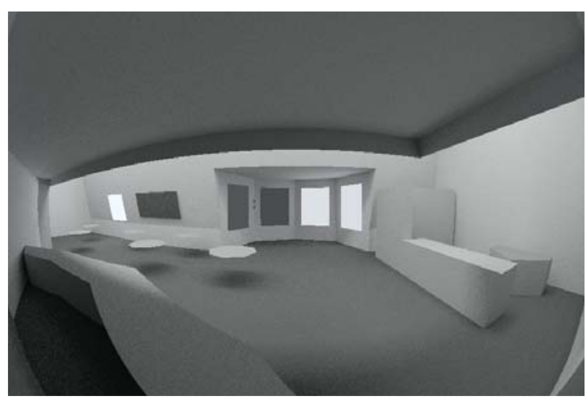

Figure 4: A combined result based on a particular time of day, year, and shading condition that took 10 seconds to generate

Computing the Daylight Matrix (D)

The calculations above rely on knowing how light is arriving at each window, which then passes through the BSDF matrix **T** for that group. These form factors are stored in the **D** matrix in Eq. (3), which relates sky patch luminances to incident window directions, accounting for external obstructions and interreflections. In fact, a separate **D** matrix is computed for each window group, since the set of directions is different for different orientations. The more general version of Eq. (3) is therefore

$$\vec{\mathbf{i}} = \sum_{g=1}^{n} \mathbf{V_g T_g D_g} \vec{\mathbf{s}} \qquad (4)$$

Where:

g = window group index
n = number of window groups

The actual calculation of **V** uses **rtcontrib** to sample outgoing ray directions for each window group, collecting results for each sky patch. To assist this process, we have written a Perl script **genklemsamp** that identifies windows with a given orientation in a given geometry file, then sends out rays with random origins distributed over their surface(s). We employed the full (145x145) Klems basis described in the WINDOW 6.1 / THERM 6.1 Research Version User Manual for our sample directions, since it corresponds to the BSDF data available to us from *WINDOW6* [Windows & Daylighting Group, 2006].

Figure 6 shows the exterior of the space we showed earlier. The circled bay window was used in the fisheye projection shown in Figure 7. We assigned a random color to the 145 Tregenza patches (plus one for the ground), and overlaid a grid corresponding to the 145 Klems patches on the window. The visible surfaces appear grayish because they see most of the sky, so the coloration averages out. Hence, the corresponding rows in our **D** matrix will have many non-zero terms. The rows that correspond to direct views of the sky will have only a few non-zero terms, since only a few Tregenza patches are visible from each. Of course, it would be unwise to generate the **D** matrix directly from such an image, as it samples only a single point on the window. Our Perl script therefore randomizes the sample ray origins over the window to obtain a good average for each matrix coefficient.

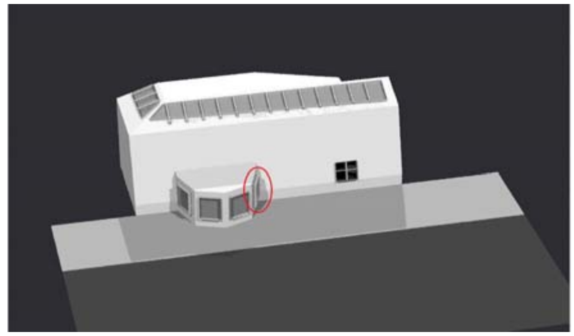

Figure 6: The exterior of our example space, indicating the window whose view is shown in Figure 7 below

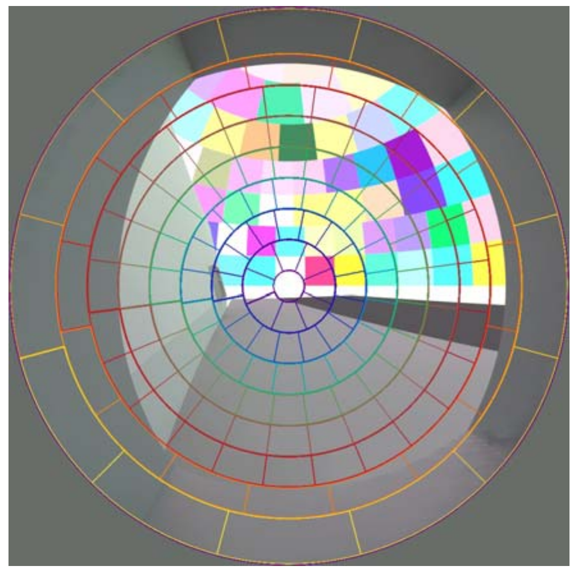

Figure 7: The grid lines divide our hemisphere into 145 patches using the full Klems basis. Randomly colored patches in the sky indicate the 145 Tregenza patches

It was discovered early on that, even if the shading system on the window is fairly diffusing and blocks any direct sunlight, 145 sky patches was not enough in cases where there was shadows cast by nearby geometry. The Tregenza resolution is roughly 12°, and we distribute the sun's energy into the three nearest patches, so the actual resolution is closer to 24°. If a neighboring building or structure is going to partially or fully block direct sun on the window, 24° is a pretty wide margin of error, and we noticed significant discrepancies in our early results. We found it necessary for many models to subdivide the sky further, and ended up using a 4x4 subdivision of the Tregenza patches developed by other researchers [Mardaljevic 2000, Bourgeois et al. 2008]. With 2305 patches (plus ground), we have an effective resolution of about 6°, corresponding roughly to a half hour in terms of solar position. Greater accuracy is of course possible with a finer subdivision, but we found this to be adequate to our needs

Sky Patch Vectors and Evaluation

Once we have our **Vg** and **Dg** matrices, and have selected the transmission matrices **Tg** for each window group, we can apply them directly in Eq. (4) or multiply and sum them together to arrive at a complete daylight coefficient matrix needed for our original Eq. (2):

$$\mathbf{C} = \sum_{g=1}^{n} \mathbf{V_g} \mathbf{T_g} \mathbf{D_g} \tag{5}$$

In either case, we need a sky patch vector **s** corresponding to the current time step in order to compute a final result vector **i**. For this purpose, we have created another Perl script **genskyvec** that takes a sky model produced by the Radiance **gensky** program or **gendaylit** by the ISE in Freiburg, Germany. The advantage of the latter program is that it takes direct and indirect solar irradiance as input and computes the sky type from these data, which one can find in reference weather files for most climates.

The final evaluation involves multiplying the combined matrix by our sky vector, which is a very fast calculation. Even when different **T** matrices are being tried at each timestep to find an optimal result, the full matrix multiplication takes only a few seconds, and a convenient tool **dctimestep** is provided for this purpose.

Using Dynamic Radiance on 61 Models

We applied the Dynamic Radiance approach to generate annual results for illuminance, sun penetration, and skyview for the Daylight Metrics project. A field survey provided detailed information to create detailed *Radiance* .rad scene files for 61 spaces in six different cities across the United States. The .rad files were created using *Ecotect v5.50*. Horizontal illuminance sensors were provide at 1 ft by 1 ft spacing, on the task level (31 inches), eye level (48 inches) and ceiling level (height varies by space)

After the models were exported from *EcoTect* the windows were grouped in each space by orientation. In addition, we further limited groups to windows which were co-planar, contained the same glass type, and the same window covering (blinds or shades where present). Lastly, BSDF files were assigned to each window group.

For the scope of this project, we limited blinds operation to only two conditions – blinds are either fully deployed or completely retracted, a deployed blind completely covers the window, while a retracted blind does not cover any portion of the window. Blinds were triggered to deploy when 2% of the horizontal 'eye level' sensors had an illuminance of 4,000 lux (roughly equivalent to 50 Watt/m2 of solar radiation) or greater when considering only sunlight as an illumination source from any given window group. One of two BSDF files were assigned to window groups depending on the characteristics of the windows in that group. A BSDF representing an un-shaded, or open window was assigned to all window groups. This "open" BSDF accounted for the visible transmittance of the glazing in the windows. If the windows in the group had blinds or shades, an additional BSDF was assigned to the group to reflect the "closed" condition. This BSDF accounted for the visible transmittance of the glazing and the associated blinds or shades. Other details of blinds assumptions used in the project can be found here [Saxena et al, 2010].

The simulations using the Dynamic Radiance approach took between 2 and 14 hours for 80% of the models with a median time of 5.2 hours. The quickest model finished in just under an hour. The space had only one window, and had little exterior context modeled. The longest model took just over 28 hours. It was a relatively large model, had 18 window groups, and was surrounded by multiple high-rise skyscrapers. Processor run times were not recorded for all models, however, of the 41 timed runs, only 3 took longer than 14 hours.

Simulation Results

The color contour plots in Figure 8 represent average monthly illuminance for each sensor on the task level illumination grid for January for a space facing south.

The plot on the left shows illuminance without blinds, while that on the right is with blinds operated as per the blinds trigger assumption. The data were averaged separately for each hourly time step from 8:00-17:00, for the months January.

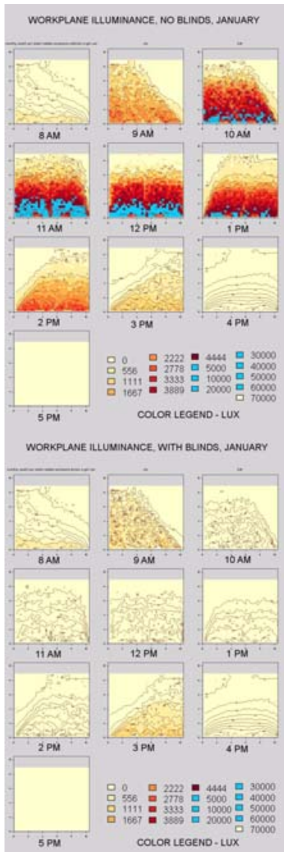

Figure 8: Average workplane illuminance in January – No blinds case (left), blinds operated case (right)

The plots clearly show that during the hours when blinds are deployed, the average illumination at the workplane is much lower with the blinds closed, as expected, but the directional nature of the light through the blinds is preserved due to the use of BSDFs.

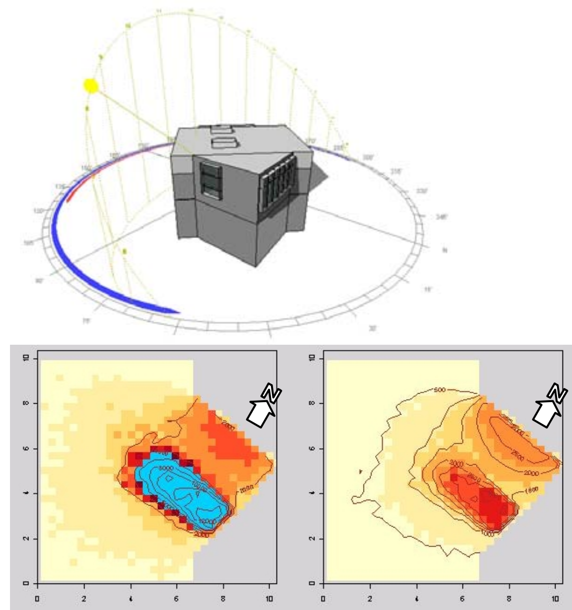

Figure 9: Illuminance distributions at 8:00 AM on July 11th - No blinds case (left), blinds operated case (right)

Figure 9 shows the 3D model and illuminance plots for a space in San Francisco at 8:00 AM on July 11th. The plot on the left is without blinds, with that on the right is with blinds operated as per the blinds trigger assumptions. The space has two windows, one facing north and another facing east. As per the rule-set for defining window groups, since each window has a different orientation, two window groups were assigned, one for each window.

The illuminance plot without blinds (left) shows that at 8:00 AM, the east-facing window is receiving direct sun (shown by blue >5000 lux), while the north-facing window receives only diffuse or reflected light.

The illuminance plot with blinds operated (right) shows that, illuminance next to the east window reduces to show that blinds have been deployed, while that next to the north-facing window reamins more or less unchanged. This result is in-line with what can be expected with two window groups. Only the blinds on the east-facing window are getting deployed, while blinds on the noth-facing window reamin open.

Advantages and Disadvantages of Dynamic Radiance

Speed and the ability to incorporate arbitrary BTDFs on windows and skylights are the principal advantages of the Dynamic Radiance method. Combining daylight coefficients with window-specific BSDF data allows us to generate annual simulations in an operationally-acceptable time-span. By splitting the daylight coefficient matrix into two matrixes, an interior- and an exterior-matrix, we are able trace light paths inside and outside the building only once and reuse the results. Then, simple matrix math gives us the resultant illumination for each point with a given window matrix (BSDF) substituted in between the interior- and an exterior-matrices. This timestep calculation can be inserted into an annual simulation system without requiring direct links to Radiance, simplifying the process as well. Any controllable shading system that can be discretized into a finite number of BSDFs may be evaluated, and the control algorithm can be simple or complex, since the calculation is so quick. This opens up the possibilites to evaluate the daylighting performance of dynamic blinds and shading systems that use moroized controls and change postion based on climtic inputs.

The Dynamic Radiance approach utilizes top-level *Radiance* component programs. These programs have an established interface and years of testing. In the event that bug fixes or enhancements are added to *Radiance*, the suite of scripts and Makefile's used to implement the Dynamic Radiance approach can be updated simply by installing the current version of *Radiance*. No compilation is necessary due to the loose coupling and standard interfaces between the programs that constitute the Dynamic Radiance approach and *Radiance* 4.0 component programs.

Despite its benefits for annual simulation and complex fenestration, the Dynamic Radiance method comes with some limitations. Firstly, it does not project exterior shadows into the space, so a partially obscured window group will pass the average light reaching its exterior, evenly distributed over the area of the window group. The window may be subdivided to compensate, but doing so increases the computation time, and determining the optimal subdivision in advance is difficult. Secondly, window-assembly light-distribution patterns are limited by the BSDF format, so any direct or redirected component is smeared over about 15° with the current standard basis. This is illustrated by Figure 10, which can be compared to Figure 2 calculated by **mkillum**. We have lost the details of the blinds, and even the shadows due to the window edges have been blurred significantly. However, this took only an hour to compute, including precalculation, and the next time step can be computed in a matter of seconds.

Figure 10: The same scene as Figure 2 computed using the Dynamic Radiance approach

Acknowledgment

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APPENDIX E: Bidirectional-Scatter-Distribution-Functions

Bi-directional scatter distribution functions (BSDF)

A full BSDF, as defined for WINDOW 6, consists of a full Klem sample, or a 145x145 matrix, defining light transmittance through a fenestration assembly. Incoming light striking the exterior surface of the assembly is represented through 145 exterior vectors. Similarly, light transmitted by and exiting the assembly is represented through 145 interior vectors. A BSDF file defines coefficients (c ≥0) to allocate light from each exterior vector to each interior vector. These coefficients are stored in a 145x145 table. Each column represents a single exterior vector, while each row represents a single interior vector. The light transmitted into the space on any one interior vector is given by Eq. (1) below

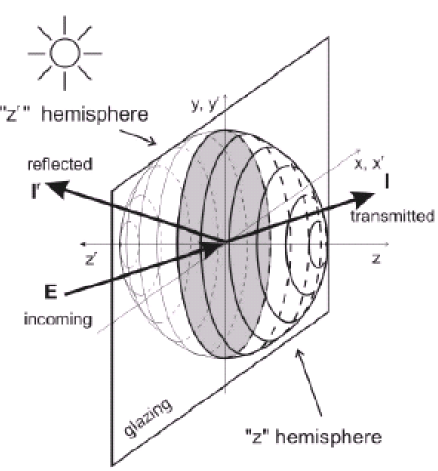
$$I_j = \sum_{k=1}^{145} c_{jk} E_k \qquad (1)$$

Where:

E_k = light along exterior vector k
I_j = light along interior vector j
c_{jk} = coefficient relating I_j to E_k which is stored in the cell located in column k, row j of the BSDF

Our implementation of the Dynamic Radiance method utilizes BSDF files to represent fenestration assemblies consisting of the glazing and window coverings. Previous research has shown BSDF data provides acceptable resolution for simulating complex fenestration assemblies. Further discussion of the file format is available from LBNL [Fernandes, 2006].

Figure E-1: Schematic Diagram Representing Vectors of a BSDF



Source: Fernandes, 2006

APPENDIX F:
Additional Results Tables

In addition to the statewide results provided in Section5, this Appendix provides results by investor owned utility (IOU) and SMUD territories, and by each climate zone in each utility territory.

Total Energy and Demand Savings Tables by Utility and Climate Zone

This section provides total energy and demand savings for all office buildings in each utility territory, and by each climate zone in each utility territory. For an explanation of the column heading, please refer to Section 5.

Table 32: Energy and Demand Savings for Each IOU Territory

LIGHTING SAVINGS Only

Results for >>	All CZs PG&E		All CZs SMUD		All CZs SCE		All CZs SDG&E	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	176.43	61.93	20.59	7.02	153.84	52.65	55.22	19.95
SOFF	59.85	22.61	6.11	2.23	82.76	29.75	35.64	13.74
LOFF	116.58	39.32	14.48	4.79	71.08	22.90	19.58	6.21

LIGHTING AND HVAC SAVINGS

Results for >>	All CZs PG&E			All CZs SMUD			All CZs SCE			All CZs SDG&E		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	194.01	80.64	(0.94)	22.59	9.33	(0.13)	177.95	69.10	(0.43)	63.98	25.17	(0.06)
SOFF	64.11	27.84	(0.21)	6.52	2.73	(0.03)	95.07	38.47	(0.12)	41.29	17.28	(0.02)
LOFF	129.90	52.81	(0.73)	16.06	6.59	(0.10)	82.88	30.63	(0.31)	22.69	7.89	(0.04)

Table 33: Energy & demand savings by IOU territory - PG&E CZs 2-5

LIGHTING SAVINGS Only

Results for >>	CZ 2 PG&E		CZ 3 PG&E		CZ 4 PG&E		CZ 5 PG&E	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	14.23	5.65	89.80	31.37	25.51	8.34	0.60	0.16
SOFF	12.83	5.15	14.03	5.43	8.32	3.15	0.60	0.16
LOFF	1.41	0.50	75.76	25.94	17.19	5.18	0.00	0.00

LIGHTING AND HVAC SAVINGS

Results for >>	CZ 2 PG&E			CZ 3 PG&E			CZ 4 PG&E			CZ 5 PG&E		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	15.11	6.94	(0.06)	98.93	41.07	(0.52)	28.31	10.88	(0.12)	0.64	0.20	(0.00)
SOFF	13.56	6.26	(0.05)	14.93	6.68	(0.04)	8.96	3.87	(0.02)	0.64	0.20	(0.00)
LOFF	1.55	0.68	(0.01)	84.01	34.38	(0.48)	19.35	7.01	(0.09)	0.00	0.00	-

Table 34: Energy and Demand Savings by IOU Territory - PG&E CZs 11-16

LIGHTING SAVINGS Only

Results for >>	CZ 11 PG&E		CZ 12 PG&E		CZ 13 PG&E		CZ 16 PG&E	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	5.64	2.13	23.69	8.13	16.23	5.88	0.74	0.27
SOFF	5.05	1.96	11.40	3.85	6.89	2.63	0.74	0.27
LOFF	0.59	0.17	12.29	4.27	9.34	3.25	0.00	0.00

LIGHTING AND HVAC SAVINGS

Results for >>	CZ 11 PG&E			CZ 12 PG&E			CZ 13 PG&E			CZ 16 PG&E		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	6.00	2.67	(0.03)	25.80	10.61	(0.13)	18.19	7.71	(0.08)	0.73	0.33	(0.01)
SOFF	5.35	2.43	(0.02)	12.16	4.73	(0.05)	7.51	3.27	(0.02)	0.73	0.33	(0.01)
LOFF	0.65	0.24	(0.00)	13.64	5.88	(0.09)	10.68	4.44	(0.05)	0.00	0.00	-

Table 35: Energy and Demand Savings by IOU Territory - SMUD CZ

LIGHTING SAVINGS Only

	CZ 12	
Results for >>	SMUD	
	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	20.59	7.02
SOFF	6.11	2.23
LOFF	14.48	4.79

LIGHTING AND HVAC SAVINGS

	CZ 12		
Results for >>	SMUD		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	22.59	9.33	(0.13)
SOFF	6.52	2.73	(0.03)
LOFF	16.06	6.59	(0.10)

Table 36: Energy and Demand Savings by IOU Territory – SCE CZs – 6-10

LIGHTING SAVINGS Only

	CZ 6		CZ 8		CZ 9		CZ 10	
Results for >>	SCE		SCE		SCE		SCE	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	47.55	15.72	44.46	14.69	34.69	11.85	16.18	6.35
SOFF	18.26	6.40	28.48	9.77	17.67	6.48	10.58	4.20
LOFF	29.29	9.32	15.98	4.93	17.03	5.37	5.60	2.15

LIGHTING AND HVAC SAVINGS

	CZ 6			CZ 8			CZ 9			CZ 10		
Results for >>	SCE			SCE			SCE			SCE		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	54.92	20.39	(0.14)	51.67	19.33	(0.10)	40.45	15.88	(0.10)	18.55	8.12	(0.04)
SOFF	20.95	8.21	(0.02)	32.97	12.64	(0.04)	20.49	8.52	(0.02)	12.07	5.38	(0.01)
LOFF	33.97	12.18	(0.12)	18.71	6.69	(0.07)	19.97	7.36	(0.08)	6.48	2.74	(0.02)

Table 37: Energy and Demand Savings by IOU Territory - SCE CZs 13-16

LIGHTING SAVINGS Only

	CZ 13		CZ 14		CZ 15		CZ 16	
Results for >>	SCE		SCE		SCE		SCE	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	4.45	1.57	4.06	1.47	0.96	0.36	1.49	0.63
SOFF	4.21	1.50	1.11	0.41	0.96	0.36	1.49	0.63
LOFF	0.23	0.07	2.95	1.06	0.00	0.00	0.00	0.00

LIGHTING AND HVAC SAVINGS

	CZ 13			CZ 14			CZ 15			CZ 16		
Results for >>	SCE			SCE			SCE			SCE		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	5.02	2.07	(0.01)	4.57	1.92	(0.02)	1.15	0.46	(0.00)	1.48	0.81	(0.01)
SOFF	4.75	1.98	(0.01)	1.24	0.53	(0.00)	1.15	0.46	(0.00)	1.48	0.81	(0.01)
LOFF	0.27	0.09	(0.00)	3.34	1.39	(0.02)	0.00	0.00	-	0.00	0.00	-

Table 38: Energy and Demand Savings by IOU Territory - SDG&E CZs

LIGHTING SAVINGS Only

	CZ 7		CZ 8		CZ 10	
Results for >>	SDG&E		SDG&E		SDG&E	
	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)	Energy Savings (GWh)	Demand Savings (MW)
All Office Bldgs	35.08	12.55	4.10	1.32	16.04	6.08
SOFF	18.41	7.24	3.75	1.19	13.48	5.31
LOFF	16.67	5.31	0.35	0.13	2.56	0.77

LIGHTING AND HVAC SAVINGS

	CZ 7			CZ 8			CZ 10		
Results for >>	SDG&E			SDG&E			SDG&E		
	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	40.66	15.84	(0.04)	4.76	1.70	(0.00)	18.62	7.73	(0.02)
SOFF	21.32	9.07	(0.01)	4.36	1.52	(0.00)	15.67	6.77	(0.01)
LOFF	19.34	6.77	(0.03)	0.41	0.17	(0.00)	2.95	0.95	(0.01)

Building Level Analysis Tables by Utility and Climate Zone

This section provides energy & demand savings per square foot of building area (building level analysis) for all office buildings in each utility territory, & by each CZ in each utility territory. For an explanation of the column heading, please refer to Section 5.

Table 39: Building Level Analysis: Energy and Demand Savings by Utility − All PG&E CZs

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.62	0.24	415.58	9,958	25%	33%	71%
SOFF	Gross WWR < .20	0.59	0.22	77.69	2,448	25%	34%	69%
	Gross WWR > .20	0.86	0.34	26.21	5,200	25%	40%	74%
	Skylight	0.92	0.41	13.12	8,337	34%	36%	97%
LOFF	Gross WWR < .20	0.31	0.10	66.67	78,909	9%	13%	69%
	Gross WWR > .20	0.42	0.15	197.20	94,692	15%	18%	80%
	Skylight	0.36	0.13	34.67	75,612	14%	16%	95%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.72	0.31	415.58	9,958	25%	33%	71%
SOFF	Gross WWR < .20	0.63	0.27	77.69	2,448	25%	34%	69%
	Gross WWR > .20	0.92	0.42	26.21	5,200	25%	40%	74%
	Skylight	0.99	0.50	13.12	8,337	34%	36%	97%
LOFF	Gross WWR < .20	0.34	0.14	66.67	78,909	9%	13%	69%
	Gross WWR > .20	0.47	0.20	197.20	94,692	15%	18%	80%
	Skylight	0.40	0.18	34.67	75,612	14%	16%	95%

Table 40: Bldg Level Analysis: Energy & Demand Savings by Utility - All SMUD CZs

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **SMUD**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.39	0.15	60.94	13,603	13%	20%	63%
SOFF	Gross WWR < .20	0.49	0.19	13.92	4,879	15%	24%	65%
	Gross WWR > .20	0.10	0.04	1.92	2,859	4%	7%	29%
	Skylight	0.22	0.09	2.63	6,663	17%	18%	98%
LOFF	Gross WWR < .20	0.18	0.07	13.15	64,966	10%	10%	67%
	Gross WWR > .20	0.39	0.13	28.90	84,152	12%	17%	71%
	Skylight	0.31	0.08	0.43	27,192	19%	19%	100%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **SMUD**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.42	0.19	60.94	13,603	13%	20%	63%
SOFF	Gross WWR < .20	0.53	0.23	13.92	4,879	15%	24%	65%
	Gross WWR > .20	0.11	0.04	1.92	2,859	4%	7%	29%
	Skylight	0.23	0.11	2.63	6,663	17%	18%	98%
LOFF	Gross WWR < .20	0.20	0.09	13.15	64,966	10%	10%	67%
	Gross WWR > .20	0.44	0.18	28.90	84,152	12%	17%	71%
	Skylight	0.35	0.11	0.43	27,192	19%	19%	100%

Table 41: Building Level Analysis: Energy and Demand Savings by Utility − All SCE CZs

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.59	0.20	382.53	6,296	20%	28%	81%
SOFF	Gross WWR < .20	0.57	0.19	102.15	2,247	19%	27%	82%
	Gross WWR > .20	0.83	0.28	36.92	6,223	20%	35%	69%
	Skylight	0.72	0.29	17.50	3,281	30%	36%	91%
LOFF	Gross WWR < .20	0.20	0.07	49.26	47,216	7%	9%	75%
	Gross WWR > .20	0.38	0.13	149.06	63,788	11%	14%	70%
	Skylight	0.43	0.14	27.64	42,265	15%	17%	92%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

All CZs

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.69	0.27	382.53	6,296	20%	28%	81%
SOFF	Gross WWR < .20	0.66	0.25	102.15	2,247	19%	27%	82%
	Gross WWR > .20	0.96	0.36	36.92	6,223	20%	35%	69%
	Skylight	0.83	0.37	17.50	3,281	30%	36%	91%
LOFF	Gross WWR < .20	0.24	0.09	49.26	47,216	7%	9%	75%
	Gross WWR > .20	0.45	0.17	149.06	63,788	11%	14%	70%
	Skylight	0.51	0.19	27.64	42,265	15%	17%	92%

Table 42: Bldg Level Analysis: Energy & Demand Savings by Utility - All SDG&E CZs

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

All CZs

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.69	0.28	143.69	4,165	26%	34%	77%
SOFF	Gross WWR < .20	0.66	0.28	43.75	1,578	26%	33%	79%
	Gross WWR > .20	0.98	0.36	11.90	2,965	22%	41%	63%
	Skylight	0.82	0.35	3.77	3,131	62%	70%	94%
LOFF	Gross WWR < .20	0.23	0.07	50.97	58,122	9%	10%	72%
	Gross WWR > .20	0.55	0.17	32.55	48,760	9%	13%	66%
	Skylight	0.56	0.18	0.76	54,195	19%	19%	99%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

All CZs

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.80	0.35	143.69	4,165	26%	34%	77%
SOFF	Gross WWR < .20	0.76	0.35	43.75	1,578	26%	33%	79%
	Gross WWR > .20	1.13	0.45	11.90	2,965	22%	41%	63%
	Skylight	0.95	0.44	3.77	3,131	62%	70%	94%
LOFF	Gross WWR < .20	0.27	0.10	50.97	58,122	9%	10%	72%
	Gross WWR > .20	0.64	0.22	32.55	48,760	9%	13%	66%
	Skylight	0.65	0.23	0.76	54,195	19%	19%	99%

Table 43: Building Level Analysis: Energy and Demand Savings by Utility − PG&E CZ2

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 2

Results for >> PG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		1.10	0.42	17.12	3,983	40%	44%	94%
SOFF	Gross WWR < .20	0.98	0.37	4.64	1,782	40%	43%	96%
	Gross WWR > .20	1.40	0.52	3.50	3,721	39%	50%	83%
	Skylight	1.19	0.53	3.79	5,352	44%	44%	100%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.18	0.05	3.92	109,476	4%	7%	81%
	Skylight	0.56	0.20	1.26	170,774	11%	14%	86%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 2

Results for >> PG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		1.27	0.55	17.12	3,983	40%	44%	94%
SOFF	Gross WWR < .20	1.03	0.45	4.64	1,782	40%	43%	96%
	Gross WWR > .20	1.48	0.63	3.50	3,721	39%	50%	83%
	Skylight	1.25	0.64	3.79	5,352	44%	44%	100%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.19	0.07	3.92	109,476	4%	7%	81%
	Skylight	0.61	0.28	1.26	170,774	11%	14%	86%

Table 44: Bldg Level Analysis: Energy & Demand Savings by Utility - PG&E CZ3

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 3

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.64	0.25	189.89	40,697	19%	26%	78%
SOFF	Gross WWR < .20	0.73	0.29	13.90	7,119	19%	29%	70%
	Gross WWR > .20	0.72	0.24	4.53	7,367	21%	30%	85%
	Skylight	0.62	0.27	4.81	8,589	24%	29%	93%
LOFF	Gross WWR < .20	0.35	0.13	31.73	148,114	10%	13%	70%
	Gross WWR > .20	0.52	0.19	118.80	98,994	18%	22%	81%
	Skylight	0.35	0.12	16.11	130,393	13%	17%	89%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 3

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.74	0.33	189.89	40,697	19%	26%	78%
SOFF	Gross WWR < .20	0.78	0.36	13.90	7,119	19%	29%	70%
	Gross WWR > .20	0.77	0.30	4.53	7,367	21%	30%	85%
	Skylight	0.66	0.33	4.81	8,589	24%	29%	93%
LOFF	Gross WWR < .20	0.39	0.17	31.73	148,114	10%	13%	70%
	Gross WWR > .20	0.58	0.25	118.80	98,994	18%	22%	81%
	Skylight	0.39	0.16	16.11	130,393	13%	17%	89%

Table 45: Building Level Analysis: Energy and Demand Savings by Utility - PG&E CZ4

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 4

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.51	0.22	70.58	9,104	22%	32%	77%
SOFF	Gross WWR < .20	0.35	0.15	8.74	1,630	21%	28%	82%
	Gross WWR > .20	1.14	0.53	7.06	4,747	29%	53%	60%
	Skylight	0.99	0.41	1.83	13,140	36%	36%	100%
LOFF	Gross WWR < .20	0.26	0.08	13.51	43,319	9%	11%	71%
	Gross WWR > .20	0.27	0.08	35.32	90,765	9%	13%	74%
	Skylight	0.44	0.17	4.13	63,761	20%	23%	95%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 4

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.59	0.29	70.58	9,104	22%	32%	77%
SOFF	Gross WWR < .20	0.38	0.18	8.74	1,630	21%	28%	82%
	Gross WWR > .20	1.23	0.65	7.06	4,747	29%	53%	60%
	Skylight	1.06	0.50	1.83	13,140	36%	36%	100%
LOFF	Gross WWR < .20	0.29	0.11	13.51	43,319	9%	11%	71%
	Gross WWR > .20	0.30	0.11	35.32	90,765	9%	13%	74%
	Skylight	0.50	0.23	4.13	63,761	20%	23%	95%

Table 46: Bldg Level Analysis: Energy & Demand Savings by Utility - PG&E CZ5

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 5

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.60	0.16	0.90	5,938	23%	30%	94%
SOFF	Gross WWR < .20	0.49	0.14	0.21	16,926	20%	24%	98%
	Gross WWR > .20	0.61	0.17	0.69	4,954	24%	31%	93%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 5

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.69	0.21	0.90	5,938	23%	30%	94%
SOFF	Gross WWR < .20	0.53	0.17	0.21	16,926	20%	24%	98%
	Gross WWR > .20	0.66	0.20	0.69	4,954	24%	31%	93%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 47: Building Level Analysis: Energy and Demand Savings by Utility − PG&E CZ11

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 11

Results for >> PG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.34	0.15	20.46	2,879	14%	29%	49%
SOFF	Gross WWR < .20	0.34	0.15	18.49	2,625	14%	29%	49%
	Gross WWR > .20	0.69	0.21	0.82	24,900	12%	28%	53%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.41	0.14	0.36	23,438	17%	25%	89%
	Gross WWR > .20	0.55	0.15	0.78	63,900	16%	23%	89%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 11

Results for >> PG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.39	0.20	20.46	2,879	14%	29%	49%
SOFF	Gross WWR < .20	0.36	0.18	18.49	2,625	14%	29%	49%
	Gross WWR > .20	0.73	0.26	0.82	24,900	12%	28%	53%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.45	0.20	0.36	23,438	17%	25%	89%
	Gross WWR > .20	0.61	0.21	0.78	63,900	16%	23%	89%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 48 Bldg Level Analysis: Energy & demand savings by Utility - PG&E CZ12

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 12

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.69	0.23	78.31	6,303	29%	35%	66%
SOFF	Gross WWR < .20	0.71	0.23	21.70	1,873	31%	36%	64%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.77	0.35	2.69	16,196	25%	25%	98%
LOFF	Gross WWR < .20	0.05	0.02	12.88	172,714	3%	3%	80%
	Gross WWR > .20	0.26	0.09	27.86	83,250	9%	11%	91%
	Skylight	0.34	0.13	13.18	50,127	13%	13%	98%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 12

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.77	0.30	78.31	6,303	29%	35%	66%
SOFF	Gross WWR < .20	0.76	0.29	21.70	1,873	31%	36%	64%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.83	0.43	2.69	16,196	25%	25%	98%
LOFF	Gross WWR < .20	0.05	0.02	12.88	172,714	3%	3%	80%
	Gross WWR > .20	0.28	0.12	27.86	83,250	9%	11%	91%
	Skylight	0.38	0.17	13.18	50,127	13%	13%	98%

Table 49: Building Level Analysis: Energy and Demand Savings by Utility − PG&E CZ13

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 13

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.61	0.24	36.53	7,017	25%	38%	78%
SOFF	Gross WWR < .20	0.75	0.32	8.22	2,702	31%	45%	82%
	Gross WWR > .20	0.42	0.14	9.61	5,263	17%	29%	75%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.40	0.14	8.19	35,791	11%	17%	58%
	Gross WWR > .20	0.42	0.16	10.52	95,087	15%	19%	54%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 13

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.75	0.33	36.53	7,017	25%	38%	78%
SOFF	Gross WWR < .20	0.82	0.39	8.22	2,702	31%	45%	82%
	Gross WWR > .20	0.45	0.18	9.61	5,263	17%	29%	75%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.46	0.19	8.19	35,791	11%	17%	58%
	Gross WWR > .20	0.49	0.21	10.52	95,087	15%	19%	54%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 50: Bldg Level Analysis: Energy & Demand Savings by Utility - PG&E CZ16

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 16

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.41	0.15	1.79	13,984	14%	14%	100%
SOFF	Gross WWR < .20	0.41	0.15	1.79	13,984	14%	14%	100%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 16

Results for >> **PG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.42	0.20	1.79	13,984	14%	14%	100%
SOFF	Gross WWR < .20	0.41	0.19	1.79	13,984	14%	14%	100%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 51: Building Level Analysis: Energy and Demand Savings by Utility − SMUD CZ12

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 12

Results for >> **SMUD**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.39	0.15	60.94	13,603	13%	20%	63%
SOFF	Gross WWR < .20	0.49	0.19	13.92	4,879	15%	24%	65%
	Gross WWR > .20	0.10	0.04	1.92	2,859	4%	7%	29%
	Skylight	0.22	0.09	2.63	6,663	17%	18%	98%
LOFF	Gross WWR < .20	0.18	0.07	13.15	64,966	10%	10%	67%
	Gross WWR > .20	0.39	0.13	28.90	84,152	12%	17%	71%
	Skylight	0.31	0.08	0.43	27,192	19%	19%	100%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 12

Results for >> **SMUD**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.42	0.19	60.94	13,603	13%	20%	63%
SOFF	Gross WWR < .20	0.53	0.23	13.92	4,879	15%	24%	65%
	Gross WWR > .20	0.11	0.04	1.92	2,859	4%	7%	29%
	Skylight	0.23	0.11	2.63	6,663	17%	18%	98%
LOFF	Gross WWR < .20	0.20	0.09	13.15	64,966	10%	10%	67%
	Gross WWR > .20	0.44	0.18	28.90	84,152	12%	17%	71%
	Skylight	0.35	0.11	0.43	27,192	19%	19%	100%

Table 52: Bldg Level Analysis: Energy & demand savings by Utility - SCE CZ6

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 6

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.62	0.23	145.78	13,751	21%	26%	77%
SOFF	Gross WWR < .20	0.62	0.22	23.67	2,887	22%	27%	78%
	Gross WWR > .20	0.70	0.25	10.66	17,033	14%	24%	73%
	Skylight	1.57	0.63	2.08	4,484	53%	55%	97%
LOFF	Gross WWR < .20	0.14	0.04	11.05	51,747	6%	7%	68%
	Gross WWR > .20	0.25	0.08	91.28	89,160	8%	11%	69%
	Skylight	0.64	0.21	7.04	94,307	18%	19%	98%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 6

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.72	0.29	145.78	13,751	21%	26%	77%
SOFF	Gross WWR < .20	0.71	0.29	23.67	2,887	22%	27%	78%
	Gross WWR > .20	0.80	0.32	10.66	17,033	14%	24%	73%
	Skylight	1.80	0.81	2.08	4,484	53%	55%	97%
LOFF	Gross WWR < .20	0.16	0.06	11.05	51,747	6%	7%	68%
	Gross WWR > .20	0.29	0.10	91.28	89,160	8%	11%	69%
	Skylight	0.74	0.27	7.04	94,307	18%	19%	98%

Table 53: Building Level Analysis: Energy and Demand Savings by Utility SCE CZ8

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 8

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.79	0.24	99.14	4,721	23%	33%	81%
SOFF	Gross WWR < .20	0.81	0.24	22.95	1,519	23%	33%	82%
	Gross WWR > .20	1.00	0.32	7.14	4,541	22%	46%	56%
	Skylight	0.83	0.32	9.02	2,968	31%	39%	92%
LOFF	Gross WWR < .20	0.18	0.06	22.68	44,924	5%	7%	69%
	Gross WWR > .20	0.16	0.05	31.64	50,188	6%	8%	51%
	Skylight	0.75	0.21	5.72	38,057	21%	24%	89%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 8

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.92	0.32	99.14	4,721	23%	33%	81%
SOFF	Gross WWR < .20	0.93	0.31	22.95	1,519	23%	33%	82%
	Gross WWR > .20	1.16	0.41	7.14	4,541	22%	46%	56%
	Skylight	0.96	0.41	9.02	2,968	31%	39%	92%
LOFF	Gross WWR < .20	0.21	0.08	22.68	44,924	5%	7%	69%
	Gross WWR > .20	0.18	0.07	31.64	50,188	6%	8%	51%
	Skylight	0.88	0.29	5.72	38,057	21%	24%	89%

Table 54: Bldg Level Analysis: Energy & Demand Savings by Utility - SCE CZ9

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 9

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.40	0.14	79.11	5,421	13%	21%	77%
SOFF	Gross WWR < .20	0.28	0.10	27.09	2,370	12%	19%	78%
	Gross WWR > .20	0.99	0.34	11.68	4,892	19%	35%	69%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.20	0.07	10.50	46,879	7%	8%	87%
	Gross WWR > .20	0.74	0.23	17.11	84,854	19%	28%	81%
	Skylight	0.19	0.07	12.73	36,409	11%	12%	95%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 9

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.47	0.19	79.11	5,421	13%	21%	77%
SOFF	Gross WWR < .20	0.32	0.14	27.09	2,370	12%	19%	78%
	Gross WWR > .20	1.15	0.45	11.68	4,892	19%	35%	69%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.23	0.09	10.50	46,879	7%	8%	87%
	Gross WWR > .20	0.87	0.32	17.11	84,854	19%	28%	81%
	Skylight	0.22	0.09	12.73	36,409	11%	12%	95%

Table 55: Building Level Analysis: Energy and Demand Savings by Utility SCE CZ10

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 10

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.46	0.18	40.76	3,832	18%	24%	89%
SOFF	Gross WWR < .20	0.48	0.19	22.90	2,550	19%	26%	89%
	Gross WWR > .20	0.22	0.07	1.71	9,808	11%	18%	80%
	Skylight	0.22	0.10	5.52	4,800	13%	15%	90%
LOFF	Gross WWR < .20	0.52	0.22	3.72	42,700	19%	22%	97%
	Gross WWR > .20	0.77	0.28	6.90	28,425	15%	20%	88%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 10

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.53	0.23	40.76	3,832	18%	24%	89%
SOFF	Gross WWR < .20	0.55	0.24	22.90	2,550	19%	26%	89%
	Gross WWR > .20	0.25	0.09	1.71	9,808	11%	18%	80%
	Skylight	0.25	0.13	5.52	4,800	13%	15%	90%
LOFF	Gross WWR < .20	0.61	0.28	3.72	42,700	19%	22%	97%
	Gross WWR > .20	0.90	0.36	6.90	28,425	15%	20%	88%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 56: Bldg Level Analysis: Energy & Demand Savings by Utility - SCE CZ13

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 13

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.50	0.20	7.34	3,619	32%	40%	88%
SOFF	Gross WWR < .20	0.48	0.17	1.10	2,088	24%	36%	90%
	Gross WWR > .20	0.49	0.17	4.04	5,019	33%	38%	90%
	Skylight	0.55	0.25	0.89	1,300	39%	46%	86%
LOFF	Gross WWR < .20	0.14	0.04	1.31	95,028	2%	4%	38%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 13

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.57	0.27	7.34	3,619	32%	40%	88%
SOFF	Gross WWR < .20	0.54	0.22	1.10	2,088	24%	36%	90%
	Gross WWR > .20	0.55	0.23	4.04	5,019	33%	38%	90%
	Skylight	0.62	0.33	0.89	1,300	39%	46%	86%
LOFF	Gross WWR < .20	0.16	0.05	1.31	95,028	2%	4%	38%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 57: Building Level Analysis: Energy and Demand Savings by Utility − SCE CZ14

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 14

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.55	0.20	7.17	9,856	16%	21%	74%
SOFF	Gross WWR < .20	0.40	0.17	1.45	9,795	15%	22%	84%
	Gross WWR > .20	0.30	0.10	1.44	5,513	9%	14%	54%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.86	0.31	2.13	8,933	22%	25%	90%
	Skylight	0.72	0.27	2.15	27,060	18%	28%	76%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 14

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.62	0.26	7.17	9,856	16%	21%	74%
SOFF	Gross WWR < .20	0.45	0.21	1.45	9,795	15%	22%	84%
	Gross WWR > .20	0.33	0.13	1.44	5,513	9%	14%	54%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.97	0.40	2.13	8,933	22%	25%	90%
	Skylight	0.81	0.35	2.15	27,060	18%	28%	76%

Table 58: Building Level Analysis: Energy and Demand Savings by Utility − SCE CZ15

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 15

Results for >> SCE

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.53	0.20	0.95	5,424	8%	19%	25%
SOFF	Gross WWR < .20	0.53	0.20	0.95	5,424	8%	19%	25%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 15

Results for >> SCE

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.65	0.26	0.95	5,424	8%	19%	25%
SOFF	Gross WWR < .20	0.64	0.26	0.95	5,424	8%	19%	25%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 59: Building Level Analysis: Energy and Demand Savings by Utility − SCE CZ16

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 16

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.76	0.33	2.30	2,306	16%	29%	75%
SOFF	Gross WWR < .20	0.82	0.35	2.04	2,295	17%	31%	74%
	Gross WWR > .20	0.32	0.14	0.26	2,400	6%	11%	83%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 16

Results for >> **SCE**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.78	0.43	2.30	2,306	16%	29%	75%
SOFF	Gross WWR < .20	0.81	0.46	2.04	2,295	17%	31%	74%
	Gross WWR > .20	0.32	0.18	0.26	2,400	6%	11%	83%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.00	0.00	0.00	0	0%	0%	0%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 60: Bldg Level Analysis: Energy & Demand Savings by Utility - SDG&E CZ7

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 7

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.42	0.18	110.43	6,257	17%	23%	72%
SOFF	Gross WWR < .20	0.37	0.17	29.99	2,050	17%	23%	73%
	Gross WWR > .20	1.01	0.37	6.35	4,088	19%	33%	65%
	Skylight	0.57	0.20	1.72	27,060	16%	27%	72%
LOFF	Gross WWR < .20	0.25	0.08	44.16	58,880	8%	9%	69%
	Gross WWR > .20	0.56	0.18	27.45	43,229	9%	13%	65%
	Skylight	0.56	0.18	0.76	54,195	19%	19%	99%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 7

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.49	0.23	110.43	6,257	17%	23%	72%
SOFF	Gross WWR < .20	0.42	0.21	29.99	2,050	17%	23%	73%
	Gross WWR > .20	1.17	0.47	6.35	4,088	19%	33%	65%
	Skylight	0.66	0.25	1.72	27,060	16%	27%	72%
LOFF	Gross WWR < .20	0.29	0.10	44.16	58,880	8%	9%	69%
	Gross WWR > .20	0.65	0.23	27.45	43,229	9%	13%	65%
	Skylight	0.65	0.23	0.76	54,195	19%	19%	99%

Table 61: Building Level Analysis: Energy and Demand Savings by Utility − SDG&E CZ8

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 8

Results for >> **SDG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		1.05	0.33	5.61	1,711	16%	23%	69%
SOFF	Gross WWR < .20	1.06	0.34	3.52	1,096	16%	23%	68%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.17	0.06	2.08	32,870	10%	12%	96%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 8

Results for >> **SDG&E**

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		1.22	0.43	5.61	1,711	16%	23%	69%
SOFF	Gross WWR < .20	1.24	0.43	3.52	1,096	16%	23%	68%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%
LOFF	Gross WWR < .20	0.19	0.08	2.08	32,870	10%	12%	96%
	Gross WWR > .20	0.00	0.00	0.00	0	0%	0%	0%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Table 62: Building Level Analysis: Energy and Demand Savings by Utility − SDG&E CZ10

LIGHTING SAVINGS Only - BUILDING LEVEL ANALYSIS

CZ 10

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.94	0.39	27.65	2,037	41%	51%	86%
SOFF	Gross WWR < .20	0.96	0.41	10.23	1,036	42%	51%	91%
	Gross WWR > .20	0.95	0.34	5.56	2,257	24%	46%	62%
	Skylight	0.84	0.36	2.05	1,800	64%	72%	95%
LOFF	Gross WWR < .20	0.16	0.05	4.72	74,419	8%	9%	94%
	Gross WWR > .20	0.27	0.08	5.09	157,138	7%	9%	82%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

CZ 10

Results for >> SDG&E

		Energy Savings per Bldg sf kWh/sf-yr	Demand Savings per Bldg sf W/sf-yr	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		1.09	0.49	27.65	2,037	41%	51%	86%
SOFF	Gross WWR < .20	1.11	0.53	10.23	1,036	42%	51%	91%
	Gross WWR > .20	1.11	0.44	5.56	2,257	24%	46%	62%
	Skylight	0.97	0.45	2.05	1,800	64%	72%	95%
LOFF	Gross WWR < .20	0.18	0.07	4.72	74,419	8%	9%	94%
	Gross WWR > .20	0.31	0.10	5.09	157,138	7%	9%	82%
	Skylight	0.00	0.00	0.00	0	0%	0%	0%

Space Level Analysis Tables by Utility and Climate Zone

This section provides energy & demand savings per square foot of space area (space level analysis) for all office buildings in each utility territory, & by each CZ in each utility territory. For an explanation of the column heading, please refer to Section 5.

Table 63: Space Level Analysis: Energy and Demand Savings by Utility − All PG&E CZs

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

All CZs

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.03	0.39	2.26	0.80	272.37	2,547	37%	45%	82%
Spaces with Net WWR < .40	0.93	0.36	2.16	0.77	167.88	2,296	35%	41%	82%
Spaces with Net WWR > .40	1.30	0.46	2.44	0.81	81.41	2,594	43%	56%	83%
Spaces with skylights	0.75	0.33	2.82	1.24	23.08	9,496	27%	28%	98%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

All CZs

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.20	0.52	2.63	1.06	272.37	2,547	37%	45%	82%
Spaces with Net WWR < .40	1.08	0.48	2.51	1.03	167.88	2,296	35%	41%	82%
Spaces with Net WWR > .40	1.51	0.61	2.84	1.08	81.41	2,594	43%	56%	83%
Spaces with skylights	0.88	0.43	3.27	1.64	23.08	9,496	27%	28%	98%

Table 64: Space Level Analysis: Energy and Demand Savings by Utility – All SMUD CZs

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

All CZs

Results for >> **SMUD**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.70	0.25	2.17	0.74	48.47	4,261	23%	31%	71%
Spaces with Net WWR < .40	0.67	0.24	2.21	0.76	36.86	4,131	21%	29%	71%
Spaces with Net WWR > .40	0.89	0.29	2.27	0.69	9.65	4,893	23%	38%	66%
Spaces with skylights	0.49	0.21	1.07	0.43	1.96	4,079	39%	40%	97%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

All CZs

Results for >> **SMUD**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.76	0.32	2.36	0.96	48.47	4,261	23%	31%	71%
Spaces with Net WWR < .40	0.73	0.31	2.40	0.99	36.86	4,131	21%	29%	71%
Spaces with Net WWR > .40	0.97	0.38	2.47	0.90	9.65	4,893	23%	38%	66%
Spaces with skylights	0.53	0.27	1.16	0.56	1.96	4,079	39%	40%	97%

Table 65: Space Level Analysis: Energy and Demand Savings by Utility − All SCE CZs

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

All CZs

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.66	0.23	2.25	0.79	286.39	2,361	22%	30%	76%
Spaces with Net WWR < .40	0.53	0.19	2.10	0.76	180.04	2,085	20%	26%	75%
Spaces with Net WWR > .40	1.01	0.33	2.73	0.85	82.21	3,009	27%	40%	73%
Spaces with skylights	0.82	0.32	2.23	0.89	24.13	3,158	34%	39%	95%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

All CZs

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.76	0.30	2.60	1.03	286.39	2,361	22%	30%	76%
Spaces with Net WWR < .40	0.61	0.24	2.43	1.00	180.04	2,085	20%	26%	75%
Spaces with Net WWR > .40	1.17	0.43	3.16	1.11	82.21	3,009	27%	40%	73%
Spaces with skylights	0.95	0.42	2.58	1.17	24.13	3,158	34%	39%	95%

Table 66: Space Level Analysis: Energy and Demand Savings by Utility − All SDG&E CZs

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

All CZs

Results for >> SDG&E

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.57	0.22	1.70	0.64	121.22	1,474	22%	28%	61%
Spaces with Net WWR < .40	0.54	0.22	1.70	0.67	89.13	1,407	24%	29%	66%
Spaces with Net WWR > .40	0.64	0.21	1.74	0.55	28.77	1,629	14%	22%	39%
Spaces with skylights	0.83	0.35	1.35	0.56	3.31	2,678	61%	69%	94%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

All CZs

Results for >> SDG&E

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.66	0.27	1.97	0.81	121.22	1,474	22%	28%	61%
Spaces with Net WWR < .40	0.63	0.27	1.97	0.84	89.13	1,407	24%	29%	66%
Spaces with Net WWR > .40	0.74	0.27	2.01	0.69	28.77	1,629	14%	22%	39%
Spaces with skylights	0.96	0.44	1.56	0.71	3.31	2,678	61%	69%	94%

Table 67: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ2

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 2

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.89	0.83	2.73	1.17	15.49	979	71%	73%	97%
Spaces with Net WWR < .40	1.99	0.87	2.68	1.14	9.93	672	75%	77%	98%
Spaces with Net WWR > .40	0.92	0.33	2.73	0.91	3.99	11,798	18%	36%	57%
Spaces with skylights	0.41	0.19	3.74	1.77	1.57	2,164	10%	10%	100%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 2

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	2.19	1.08	3.16	1.52	15.49	979	71%	73%	97%
Spaces with Net WWR < .40	2.30	1.13	3.10	1.49	9.93	672	75%	77%	98%
Spaces with Net WWR > .40	1.07	0.43	3.16	1.18	3.99	11,798	18%	36%	57%
Spaces with skylights	0.47	0.25	4.32	2.30	1.57	2,164	10%	10%	100%

Table 68: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ3

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 3

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.17	0.42	2.46	0.83	101.88	2,353	39%	49%	85%
Spaces with Net WWR < .40	0.87	0.30	2.45	0.82	56.58	2,879	28%	34%	83%
Spaces with Net WWR > .40	1.44	0.51	2.48	0.84	40.22	1,757	49%	61%	87%
Spaces with skylights	0.72	0.32	2.15	0.94	5.08	6,895	29%	33%	95%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 3

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.36	0.56	2.87	1.12	101.88	2,353	39%	49%	85%
Spaces with Net WWR < .40	1.01	0.41	2.86	1.10	56.58	2,879	28%	34%	83%
Spaces with Net WWR > .40	1.68	0.69	2.89	1.13	40.22	1,757	49%	61%	87%
Spaces with skylights	0.84	0.43	2.51	1.26	5.08	6,895	29%	33%	95%

Table 69: Space Level Analysis: Energy and Demand Savings by Utility – PG&E CZ4

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 4

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.67	0.23	2.18	0.71	51.56	3,285	23%	33%	76%
Spaces with Net WWR < .40	0.46	0.16	2.04	0.66	27.79	2,643	19%	26%	77%
Spaces with Net WWR > .40	1.08	0.37	2.42	0.78	19.32	4,151	30%	48%	70%
Spaces with skylights	1.26	0.52	2.75	1.11	4.45	8,433	45%	45%	99%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 4

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.78	0.32	2.55	0.96	51.56	3,285	23%	33%	76%
Spaces with Net WWR < .40	0.54	0.22	2.39	0.90	27.79	2,643	19%	26%	77%
Spaces with Net WWR > .40	1.26	0.50	2.83	1.06	19.32	4,151	30%	48%	70%
Spaces with skylights	1.47	0.71	3.22	1.50	4.45	8,433	45%	45%	99%

Table 70: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ5

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 5

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.68	0.19	3.64	1.08	0.90	1,752	19%	25%	92%
Spaces with Net WWR < .40	0.68	0.19	3.64	1.08	0.90	1,752	19%	25%	92%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 5

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.78	0.24	4.20	1.39	0.90	1,752	19%	25%	92%
Spaces with Net WWR < .40	0.78	0.24	4.20	1.39	0.90	1,752	19%	25%	92%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 71: Space Level Analysis: Energy and Demand Savings by Utility – PG&E CZ11

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 11

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.37	0.15	1.43	0.52	13.98	1,939	16%	31%	57%
Spaces with Net WWR < .40	0.37	0.15	1.42	0.52	13.16	1,833	16%	31%	57%
Spaces with Net WWR > .40	0.69	0.21	2.94	0.86	0.82	24,900	12%	28%	53%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 11

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.43	0.21	1.64	0.70	13.98	1,939	16%	31%	57%
Spaces with Net WWR < .40	0.43	0.21	1.64	0.70	13.16	1,833	16%	31%	57%
Spaces with Net WWR > .40	0.80	0.29	3.38	1.16	0.82	24,900	12%	28%	53%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 72: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ12

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 12

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.72	0.24	1.94	0.62	53.67	3,324	30%	36%	86%
Spaces with Net WWR < .40	0.70	0.23	1.86	0.59	37.90	2,607	30%	36%	86%
Spaces with Net WWR > .40	1.00	0.32	2.76	0.88	3.78	3,255	30%	39%	86%
Spaces with skylights	0.78	0.34	2.51	1.02	11.99	27,052	27%	28%	98%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 12

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.82	0.32	2.19	0.81	53.67	3,324	30%	36%	86%
Spaces with Net WWR < .40	0.79	0.30	2.09	0.77	37.90	2,607	30%	36%	86%
Spaces with Net WWR > .40	1.13	0.42	3.11	1.15	3.78	3,255	30%	39%	86%
Spaces with skylights	0.88	0.44	2.82	1.33	11.99	27,052	27%	28%	98%

Table 73: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ13

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 13

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.58	0.22	1.71	0.62	33.10	4,080	22%	32%	67%
Spaces with Net WWR < .40	0.59	0.23	1.64	0.62	19.83	3,411	23%	33%	64%
Spaces with Net WWR > .40	0.55	0.18	1.89	0.59	13.27	5,776	19%	29%	74%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 13

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.70	0.29	2.09	0.82	33.10	4,080	22%	32%	67%
Spaces with Net WWR < .40	0.72	0.31	2.00	0.84	19.83	3,411	23%	33%	64%
Spaces with Net WWR > .40	0.67	0.24	2.31	0.80	13.27	5,776	19%	29%	74%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 74: Space Level Analysis: Energy and Demand Savings by Utility − PG&E CZ16

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 16

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.41	0.15	3.05	1.12	1.79	13,984	14%	14%	100%
Spaces with Net WWR < .40	0.41	0.15	3.05	1.12	1.79	13,984	14%	14%	100%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 16

Results for >> **PG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.42	0.20	3.14	1.46	1.79	13,984	14%	14%	100%
Spaces with Net WWR < .40	0.42	0.20	3.14	1.46	1.79	13,984	14%	14%	100%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 75: Space Level Analysis: Energy and Demand Savings by Utility – SMUD CZ12

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 12

Results for >> **SMUD**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.70	0.25	2.17	0.74	48.47	4,261	23%	31%	71%
Spaces with Net WWR < .40	0.67	0.24	2.21	0.76	36.86	4,131	21%	29%	71%
Spaces with Net WWR > .40	0.89	0.29	2.27	0.69	9.65	4,893	23%	38%	66%
Spaces with skylights	0.49	0.21	1.07	0.43	1.96	4,079	39%	40%	97%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 12

Results for >> **SMUD**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.76	0.32	2.36	0.96	48.47	4,261	23%	31%	71%
Spaces with Net WWR < .40	0.73	0.31	2.40	0.99	36.86	4,131	21%	29%	71%
Spaces with Net WWR > .40	0.97	0.38	2.47	0.90	9.65	4,893	23%	38%	66%
Spaces with skylights	0.53	0.27	1.16	0.56	1.96	4,079	39%	40%	97%

Table 76: Space Level Analysis: Energy and Demand Savings by Utility − SCE CZ6

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 6

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.69	0.23	2.54	0.85	91.39	2,971	21%	28%	73%
Spaces with Net WWR < .40	0.56	0.19	2.45	0.85	42.63	2,563	21%	26%	73%
Spaces with Net WWR > .40	0.82	0.26	2.65	0.83	44.63	3,303	20%	29%	71%
Spaces with skylights	1.52	0.61	2.87	1.11	4.13	6,762	49%	50%	99%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 6

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.80	0.30	2.93	1.10	91.39	2,971	21%	28%	73%
Spaces with Net WWR < .40	0.65	0.25	2.82	1.11	42.63	2,563	21%	26%	73%
Spaces with Net WWR > .40	0.95	0.34	3.05	1.08	44.63	3,303	20%	29%	71%
Spaces with skylights	1.75	0.79	3.31	1.44	4.13	6,762	49%	50%	99%

Table 77: Space Level Analysis: Energy and Demand Savings by Utility – SCE CZ8

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 8

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.85	0.27	2.69	0.89	77.48	2,561	25%	35%	80%
Spaces with Net WWR < .40	0.72	0.22	2.59	0.87	51.46	2,518	21%	30%	78%
Spaces with Net WWR > .40	1.33	0.40	3.27	0.94	14.57	2,789	31%	45%	76%
Spaces with skylights	0.92	0.35	2.45	0.95	11.45	2,494	36%	42%	94%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 8

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.00	0.36	3.13	1.18	77.48	2,561	25%	35%	80%
Spaces with Net WWR < .40	0.84	0.29	3.02	1.15	51.46	2,518	21%	30%	78%
Spaces with Net WWR > .40	1.55	0.53	3.81	1.24	14.57	2,789	31%	45%	76%
Spaces with skylights	1.07	0.46	2.85	1.26	11.45	2,494	36%	42%	94%

Table 78: Space Level Analysis: Energy and Demand Savings by Utility − SCE CZ9

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 9

Results for >> SCE

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.56	0.21	1.76	0.64	65.00	1,825	21%	30%	68%
Spaces with Net WWR < .40	0.40	0.15	1.57	0.61	42.55	1,558	16%	22%	65%
Spaces with Net WWR > .40	1.15	0.39	2.42	0.78	16.90	2,174	36%	56%	75%
Spaces with skylights	0.46	0.16	1.80	0.63	5.56	10,488	25%	27%	95%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 9

Results for >> SCE

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.66	0.28	2.06	0.87	65.00	1,825	21%	30%	68%
Spaces with Net WWR < .40	0.46	0.21	1.84	0.82	42.55	1,558	16%	22%	65%
Spaces with Net WWR > .40	1.34	0.52	2.82	1.04	16.90	2,174	36%	56%	75%
Spaces with skylights	0.54	0.21	2.10	0.84	5.56	10,488	25%	27%	95%

Table 79: Space Level Analysis: Energy and Demand Savings by Utility – SCE CZ10

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 10

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.49	0.19	2.01	0.76	35.24	1,877	23%	28%	89%
Spaces with Net WWR < .40	0.48	0.19	1.95	0.74	28.83	1,697	23%	28%	88%
Spaces with Net WWR > .40	0.89	0.32	4.06	1.34	5.38	8,404	17%	25%	83%
Spaces with skylights	0.40	0.18	1.78	0.80	1.03	900	22%	22%	100%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 10

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.56	0.25	2.31	0.97	35.24	1,877	23%	28%	89%
Spaces with Net WWR < .40	0.55	0.24	2.24	0.94	28.83	1,697	23%	28%	88%
Spaces with Net WWR > .40	1.02	0.41	4.67	1.71	5.38	8,404	17%	25%	83%
Spaces with skylights	0.46	0.23	2.05	1.02	1.03	900	22%	22%	100%

Table 80: Space Level Analysis: Energy and Demand Savings by Utility − SCE CZ13

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 13

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.43	0.17	1.09	0.41	7.05	2,571	29%	35%	66%
Spaces with Net WWR < .40	0.40	0.14	1.06	0.36	6.16	2,992	26%	31%	60%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.55	0.25	1.19	0.57	0.89	1,300	39%	46%	86%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 13

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.50	0.23	1.25	0.55	7.05	2,571	29%	35%	66%
Spaces with Net WWR < .40	0.45	0.19	1.21	0.49	6.16	2,992	26%	31%	60%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.62	0.34	1.36	0.76	0.89	1,300	39%	46%	86%

Table 81: Space Level Analysis: Energy and Demand Savings by Utility – SCE CZ14

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 14

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.57	0.21	2.54	0.92	7.03	7,864	17%	24%	75%
Spaces with Net WWR < .40	0.55	0.20	2.49	0.90	5.96	7,312	17%	24%	75%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.74	0.28	2.98	1.10	1.07	13,530	19%	29%	78%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 14

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.64	0.27	2.84	1.19	7.03	7,864	17%	24%	75%
Spaces with Net WWR < .40	0.62	0.26	2.79	1.17	5.96	7,312	17%	24%	75%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.83	0.37	3.34	1.43	1.07	13,530	19%	29%	78%

Table 82: Space Level Analysis: Energy and Demand Savings by Utility – SCE CZ15

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 15

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.71	0.26	2.08	0.64	0.90	3,456	11%	27%	32%
Spaces with Net WWR < .40	0.97	0.37	2.88	0.87	0.16	1,800	15%	41%	44%
Spaces with Net WWR > .40	0.58	0.21	1.67	0.52	0.75	4,284	9%	20%	26%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 15

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.86	0.35	2.52	0.84	0.90	3,456	11%	27%	32%
Spaces with Net WWR < .40	1.18	0.49	3.49	1.15	0.16	1,800	15%	41%	44%
Spaces with Net WWR > .40	0.70	0.28	2.03	0.69	0.75	4,284	9%	20%	26%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 83: Space Level Analysis: Energy and Demand Savings by Utility − SCE CZ16

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 16

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.60	0.26	3.41	1.40	2.30	1,144	13%	23%	84%
Spaces with Net WWR < .40	0.60	0.26	3.41	1.40	2.30	1,144	13%	23%	84%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 16

Results for >> **SCE**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.61	0.33	3.48	1.82	2.30	1,144	13%	23%	84%
Spaces with Net WWR < .40	0.61	0.33	3.48	1.82	2.30	1,144	13%	23%	84%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 84: Space Level Analysis: Energy and Demand Savings by Utility − SDG&E CZ7

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 7

Results for >> **SDG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.46	0.17	1.45	0.55	93.78	1,468	19%	23%	55%
Spaces with Net WWR < .40	0.42	0.17	1.42	0.57	67.86	1,420	21%	24%	61%
Spaces with Net WWR > .40	0.56	0.19	1.54	0.49	24.67	1,541	13%	20%	37%
Spaces with skylights	0.74	0.25	2.61	0.87	1.26	13,082	24%	31%	84%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 7

Results for >> **SDG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.53	0.22	1.68	0.69	93.78	1,468	19%	23%	55%
Spaces with Net WWR < .40	0.49	0.21	1.64	0.72	67.86	1,420	21%	24%	61%
Spaces with Net WWR > .40	0.65	0.24	1.79	0.62	24.67	1,541	13%	20%	37%
Spaces with skylights	0.86	0.32	3.02	1.10	1.26	13,082	24%	31%	84%

Table 85: Space Level Analysis: Energy and Demand Savings by Utility – SDG&E CZ8

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 8

Results for >> SDG&E

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.90	0.29	4.01	1.27	5.56	1,445	14%	20%	67%
Spaces with Net WWR < .40	0.90	0.29	4.01	1.27	5.56	1,445	14%	20%	67%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 8

Results for >> SDG&E

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.05	0.37	4.66	1.66	5.56	1,445	14%	20%	67%
Spaces with Net WWR < .40	1.05	0.37	4.66	1.66	5.56	1,445	14%	20%	67%
Spaces with Net WWR > .40	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%
Spaces with skylights	0.00	0.00	0.00	0.00	0.00	0	0%	0%	0%

Table 86: Space Level Analysis: Energy and Demand Savings by Utility − SDG&E CZ10

LIGHTING SAVINGS Only - SPACE LEVEL ANALYSIS

CZ 10

Results for >> **SDG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	0.97	0.40	2.20	0.88	21.87	1,510	40%	51%	86%
Spaces with Net WWR < .40	0.92	0.39	2.10	0.88	15.71	1,345	40%	49%	88%
Spaces with Net WWR > .40	1.41	0.45	3.59	1.15	4.11	2,477	25%	46%	63%
Spaces with skylights	0.84	0.36	1.24	0.54	2.05	1,800	64%	72%	95%

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

CZ 10

Results for >> **SDG&E**

	Energy Savings per Space sf kWh/sf-yr	Demand Savings per Space sf W/sf-yr	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Demand Savings per Primary Daylit Zone sf W/sf-yr	Total Space Area Msf	Average Space area sf	% Space area in primary daylit zone %	% Space area in all daylit zones %	% Energy savings - primary daylit zones %
All Daylit Office Spaces	1.12	0.50	2.55	1.11	21.87	1,510	40%	51%	86%
Spaces with Net WWR < .40	1.06	0.50	2.43	1.10	15.71	1,345	40%	49%	88%
Spaces with Net WWR > .40	1.63	0.56	4.15	1.44	4.11	2,477	25%	46%	63%
Spaces with skylights	0.97	0.45	1.44	0.67	2.05	1,800	64%	72%	95%